Ancient Indian Astronomy

and contributions of

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Samanta Chandra Sekhar
1835 - 1904

Dedication

In the memory of
Professor Kanhu Charan Mishra
Founder-Director, Institute of Orissan Culture,
Bhubaneswar, Orissa

Edited by
Professor L. Satpathy

under the aegis of

Institute of Orissan Culture, Bhubaneswar
&
Samanta Chandra Sekhar Amateur Astronomers' Association, Bhubaneswar

PREFACE

Pursuit of Astronomy as science has been undertaken in India right from the Vedic age. The tradition of its systematic study on a strong scientific basis, commenced with Aryabhata in 5th century AD. In this tradition, Samanta Chandra Sekhar(1835-1904) was the last link in the long chain of astronomers India produced, in a period spanning over a millennium and half. It will be interesting and also inspiring to know the ultimate status of the knowledge of the sky, achieved by Indian astronomers through naked-eye observations, in their long quest of several thousand years. In this regard the life and work of Samanta Chandra Sekhar (SCS) presents us with the best prospect due to the following:

(i) He being the last naked-eye astronomer of the *Siddhantic* tradition, his treatise *Siddhānta Darpana* would represent the state-of-the-art and the zenith of success finally reached in this branch of science.

(ii) Without any formal education, working in mid-nineteenth century in a remote village, he was unaware of the modern development of western science and had not seen a telescope until his very old age. Hence, we have the opportunity of judging his work properly through a litmus test, by carrying out a comparison with the results of western astronomy arrived at by the use of telescope and other optical devices then. Such a test becomes possible and meaningful in case of Samanta Chandra Sekhar only, because of advent of modern science in seventeenth century whose triumphant march had an overlap with the epoch of his research.

The book describes how Samanta Chandra Sekhar fulfilled his historic role of identifying the errors accumulated over the ages in this branch of knowledge which he eradicated, and made all out effort to bring the subject to its final perfection. The discoveries of three anomalies in the motion of the moon, hiking of the Earth-Sun distance by more than ten times the value taken by his predecessors, and his novel planetary model with heliocentric motion of the planets are some of his major contributions, which mainly helped him in accurate predictions of solar and lunar eclipses, the hallmark of a successful astronomical work. He richly deserves to be put in the same class of the four great Indian Hindu astronomers Āryabhata, Varāhamihira, Brahmagupta and Bhāskar.

Although this branch of science has been superseded now by modern Astronomy, nevertheless, it has served Indian society in the past, and still continues to do so in some parts of our country. The principal aim of this book has been to create awareness of the final achievements of Ancient Indian Astronomy in qualitative and quantitative terms, and thereby accord the rightful place in it to Samanta Chandra Sekhar.

Right from childhood, I have been overwhelmed with the legendary fame of Samanta Chandra Sekhar as an astronomer and astrologer who was well-known in

every nook and corner of Orissa. My feeling got a rude shock in 1992 when I happened to meet noted astrophysicists Prof.A. R. Prasanna of Physical Research Laboratory, Ahmedabad, late Prof. N. C. Rana and Prof. J. V. Narlikar of Inter University Centre for Astronomy & Astrophysics (IUCAA), Pune and came to know that they were unaware of SCS and his work. On further enquiry from colleagues working elsewhere in the country, the grim reality soon dawned upon me that he is hardly known outside the State of Orissa.

A firm resolve grew in me to find out what is unique about the contribution of SCS to Ancient Indian Astronomy, and then place it, before the scientists of our country with the conviction that it is only they, and not the media, who can accord him the rightful place in this field. With this view, research on SCS was initiated in collaboration with Dr. P. C. Naik of Pathani Samant Planetarium (PSP), Bhubaneswar and subsequently Samanta Chandra Sekhar Amateur Astronomers' Association(SCAAA) was founded in 1993 by the joint effort of some scientists from Institute of Physics, Utkal University, PSP and Surjanika to partly sustain this effort. The attention of Prof. J. V. Narliker and Prof. R. Kochar was drawn in 1993 to the contribution of SCS, who promptly recognised its importance, and referred it in glowing terms in their two books: (i) **Astronomy in India: Past, Present and Future** and (ii) **Astronomy in India: A Perspective**. In 1995, SCAAA in association with PSP, hosted *Vth All India Amateur Astronomers' meet* at Bhubaneswar in which contributions of SCS was presented before about 300 delegates comprising professional and amateur astronomers and scientists. The results of our investigation were published in reputed national science journals in the form of two articles entitled "*Samanta Chandra Sekhar: Life and Work*" and "*Samanta Chandra Sekhar: The Great Naked-Eye Astronomer*" in "**Current Science**" and "**Bulletin of the Astronomical Society of India**" in 1995 and 1998 respectively. In the "*National Conference on 500 years of Tantra Sangraha*" held at Madras University in March 2000 an invited paper entitled "*Samanta Chandra Sekhar and his treatise Siddhānta Darpan*" was presented. *The National Symposium on Ancient Indian Astronomy and Samanta Chandra Sekhar* was organised on 9th February, 1997 jointly by SCAAA and The Institute of Orissan Culture, Bhubaneswar in which scientists from some of the major research institutes and universities of our country participated. The present volume grew out of the deliberations in this symposium and invited articles from some reputed scientists in India and abroad, who have the knowledge and appreciation of the work of Samanta Chandra Sekhar. The untiring zeal of the octogenarian Professor Kahnu Charan Mishra, the Director of Orissan Institute of Culture provided the much needed impetus for this successful conference. His support and encouragement to bring out this volume has continued to remain a beacon for me after his passing away on 5th December, 2001.

It is a matter of great satisfaction and happiness that recently the Government of India issued a commemorative postage stamp in honour of Samanta Chandra Sekhar on 11th June, 2001 as a formal recognition of his singular contribution to Ancient Indian Astronomy.

For developing an integral perspective of the subject by the readers , allied topics

related to the development of astronomy in ancient civilization and astronomical studies by Galileo etc. have been included in this book. Hopefully, these topics will provide the backdrop for the proper comprehension of this book.

Astronomy originated in the curious mind of the man imparting strong impulse to understand the universe around him. The *Siddhāntic* Astronomy of India is concerned with the question of origin (*srushthi*) and desolution (*pralaya*) of the universe. Keeping this in view, for a wholesome picture, some related modern topics like unification of the forces and evolution of universe, microscopic view of the universe and the concept of parallel universe, written in popular style by international experts, have been included.

It is sincerely hoped that scholars of astronomy and laymen alike, will find the book useful. The effort will be considered as amply rewarded, if it succeeds in leaving an impression on the readers about the true picture of the final achievement of Ancient Indian Astronomy and the role of Samanta Chandra Sekhar in it.

I would like to express my gratitude to Prof. J. C. Pati of University of Maryland for his suggestion and inspiration to broaden the scope of this book. My thanks are due to Prof. D. P. Roy of Tata Institute of Fundamental Research whose continued appreciation and encouragement sustained this effort. It is indeed difficult to adequately express my thanks to late Prof. N. C. Rana of IUCAAA for his invaluable support in the proper evaluation of the contribution of SCS. I am thankful to the members of SCAAA, in particular to Prof. L. P. Singh, Dr. P. Naik and Dr. P. Mishra, for their enthusiasm and interest in the work of Samanta Chandra Sekhar. I am grateful to Prof. Rajkishor Mishra for his interest in this work and his all-out support in the publication of this book.

I would like to thank profously Mr. D. Pradhan of the Institute of Physics for the development of the software to bring this book to the present form.

L. Satpathy

Contents



Lakshmidhar Satpathy (b. 1939) had his school education in Jagannath High School, Sukinda, Orissa from where he passed Matriculation in 1956. Studying in Revenshaw College, Cuttack, he received B.Sc. (Hons.) (1960) and M.Sc. (Physics) (1962) from Utkal University. He carried out research in Saha Institute of Nuclear Physics, Calcutta and obtained his Ph. D. degree in theoretical nuclear physics from Calcutta University in 1968. After post-doctoral research work in Laval University, Canada; Muenster University and KFA, Juelich in Germany, he joined Berhampur University in 1971. In 1975 he moved to the newly established Institute of Physics, Bhubaneswar where he rose to the position of full Professor in 1980 and continued in that position till his retirement in 1999. He worked as Emeritus Professor in Institute of Physics during 1999-2001 and thereafter he has been continuing as Emeritus Scientist, CSIR, Govt. of India. Prof. Satpathy has worked as guest scientist/professor in McGill University, Montreal; Michigan State University, USA; Hahn Meitner Institute, Berlin; Tuebingen University, Germany; Neils Bohr Institute, Copenhagen; International Centre for Theoretical Physics (ICTP), Trieste; and KFA, Juelich, Germany etc. He is Founder President of Samanta Chandra Sekhar Amateur Astronomers' Association, Bhubaneswar. Besides Nuclear Physics he is interested in Ancient Indian Astronomy. He has been twice nominated as Associate Member of ICTP, Trieste, Italy. He is recipient of Dr. Meghnad Saha Memorial Medal, Asiatic Society, India; Kamal Kumari National Award for Science and Technology, Kamal Kumari Foundation, Assam; Samanta Chandra Sekhar Award of Govt. of Orissa and Orissa Vigyan Academy; and Nandighosh Samman, Nandighosh, Orissa.

Samanta Chandra Sekhar and his Contributions to Ancient Indian Astronomy

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1 Introduction

There is hardly anybody who has not wondered at the myriads of twinkling stars, blue expanse of the limitless sky, red and scarlet twilight and the fascinating phenomena involving Sun, Moon, Planets, Comets, Nebulae and falling Meteorites etc. The first and foremost question that comes to the mind of a child is, why the Moon does not fall like an apple from a tree. Such wonderment has set the prehistoric man into thinking about the mysteries of the astronomical phenomena and would continue to do so till eternity. Astronomy is a subject which is as old as human civilization itself. In India, right from the Vedic age, research in astronomy has been pursued in great earnest.

Extensive discussions on astronomy can be found in *Rig Veda* which is believed to be the oldest of all the Vedas written about 8000 years back, and also in *Taittriya Samhitā* and *Satapath-Brāhman.* In Vedic age the principal preoccupation of people was performance of *yagna* and many other religious rites at auspicious moments prescribed by the *shāstras.* Therefore it was essential to have accurate knowledge of time in order to predict such moments in advance. Thus astronomy in that period was mainly the science of time determination. Since time intervals are naturally defined by the period of revolution of the Moon and the Sun, there was great impetus to study their motion. Ancient Indian Astronomy can be classified into two main areas - the Vedic astronomy and the post Vedic astronomy.

In Vedic period many *siddhāntas* are believed to have been originated from divine sources without any definite authors like the Vedas and Upanishads. They are supposed to have been written by unknown *rishis* whom astronomical truths have been revealed by God. There are eighteen *sidhāntas* like *Sūrya Siddhānta, Vyās Siddhānta* and *Parāsar Siddhānta* etc. without definite authorship analogous to eighteen *purānas* of Hindu mythology. Amongst all the ancient works of astronomy with known authors, the oldest one is *Vedānga Jyotish* written by Lagadh around 1400BC.

In the post Vedic period, the earliest and most celebrated astronomer is Āryabhata of 5th century AD, the founder of the theory of Earth's daily rotation. He succeeded in laying the foundation of astronomy giving quite accurate astronomical parameters and better methods of calculation in this field. He wrote the book Āryabhatiya which occupies a pivotal position amongst the classics on astronomical works. The galaxy of astronomers born in India includes geniuses like Āryabhata, Varāhmihira,

Brahmagupta and Bhāskara, who worked and enriched this field in a period spanning from 5th to 12th century AD. The tradition of Siddhāntic astronomy continued beyond 12th century right up to the beginning of 20th century finally coming to an end with Samanta Chandra Sekhar(1835-1904) of Orissa and his treatise *Siddhānta Darpana*[1]. He occupies a place of special importance in this tradition, being the last link in the long chain of astronomers. In every branch of science, the successive scientists have to improve over the works of their predecessors and add newer knowledge to the field through their own research. This culture, more or less universal, is inherent in the very nature of the evolution of all branches of knowledge. This naturally puts a heavy burden on Samanta Chandra Sekhar(some times to be referred as Chandra Sekhar and also Samanta) who had the onerous responsibility to identify the errors accumulated over ages in this branch, and eradicate them, and make all out improvements to bring the subject to its final state of perfection and glory. As will be shown in this article, Chandra Sekhar fulfilled this historic role with distinction. He fabricated ingenious instruments for precision astronomical observations, collected data of unprecedented accuracy, devised new methods of calculation and gave new model of planetary system. All his work without the use of telescope or any other optical instruments, whose existence during his time he was unaware of, was in line with the work of his predecessors carried out centuries before. It is no exaggeration to say that with his life-long effort, Siddhāntic astronomy reached the zenith of its glory, before finally being consigned to history. The international journal *Nature*[2] in 1899, has not only compared Chandra Sekhar with Tycho but eulogised him to be even greater than Tycho[1546-1601].

It must be recognised that astronomy gave birth to the laws of motion in dynamics, paving the foundation for the emergence of modern science through the successive works of Copernicus, Tycho Brahe, Kepler, Galileo and Newton. The astronomical data painstakingly collected by Tycho Brahe was analysed by his famous assistant Kepler who had joined him in 1600 AD. The analysis led to the discovery of three laws (solely warranted to describe these data) which go by the name of Kepler. The understanding of these three empirical laws at a fundamental level posed the greatest challenge to the human intellect in seventeenth century culminating in the discovery of Newton's laws of motion and thereby laying the foundation of modern science. Thus, astronomy has been rightly called the mother of all sciences. India sadly missed this development inspite of its great tradition and heritage in astronomy spread over several millennia, due to many factors related to sociological, cultural and historic forces.

2 Life

2.1 Brief sketch

Samanta Chandra Sekhar was born on 13th December, 1835 corresponding to *Pausha Krishna Astami* of the Saka year 1957 in the royal family of the erstwhile princely state

Khandpara in Orissa. It was then one of the twenty-six princely states called *Gadajat* ruled by a dynastic king, enjoying some degree of autonomy under the British rule. It was a small state with an area of 244 square miles only, having its capital in the small township of Khandapara, situated about sixty miles west of Bhubaneswar surrounded by hills and jungles. This kingdom was founded in 1599 and was being ruled at the time of Samanta, by his nephew, the eleventh king named Natabar Singh Mardaraj. Samanta's father Shyamabandhu, and mother Bishnumali, were a very pious couple. They had nine daughters and one son before the birth of Chandra Sekhar. Since two daughters and the only son then had died in infancy, they had named Chandra Sekhar as Pathani Samanta also, who is popularly known in Orissa by that name. From the very childhood, he showed extraordinary qualities. At the age of four, he spotted the planet Venus in the sky during the day. In those days, it was considered inauspicious to see a star in the sky during the day time. So his father had to perform elaborate *Yagna* before Lord Jagannath to get rid of the sin. He received primary education in Sanskrit from a Brahmin teacher. He studied Sanskrit Grammer,*Smritis, Purānas, Darshan* and the original texts of many *Kavyās* . When he was ten year old, one of his uncles taught him a little of astrology and showed him some of the stars in the sky. Thereafter, Samanta started teaching himself *Lilābati, Bijaganita, Jyotisha* and *Vyākarana* etc, and more importantly, the ancient astronomical works like *Sūrya Siddhānta* and *Siddhānta Siromani* from the family library.

At the age of fifteen, he began to check the predictions of the *Siddhāntas* with his astronomical observations. He was utterly surprised to find that the predictions of the classics like *Siddhānta Siromani* and *Sūrya Siddhānta* did not agree with his observations. The stars and planets, neither appeared at the right place in the sky, nor at right time, as per the calculations. Disagreement between repeated calculations and observations, finally confirmed him that ancient *Siddhāntas* have errors. This kind of conviction on the part of a boy at the tender age of fifteen against the time honoured age-old scientific treatises, is undoubtedly rare indeed.Young Chandra Sekhar resolved to rectify all those errors accumulated in Indian astronomy over thousands of years. The major hurdles on his way were, getting the right instruments for observation. Ancient Indian works did not give details of instruments or methods of measurements explicitly, except some hints here and there. He devised his own instruments for the measurement of time,height of distant objects,latitude and longitude of heavenly bodies etc. His passion for precision and accuracy was unbelievable. He constructed as many as ten types of instruments for measuring time. His most well known instrument is *Mana Yantra* which is very simple, yet very versatile. Commencing from the age of fifteen, Samanta went on making observations and devising formulae for astronomical calculation for eight years. At the age of twenty-three, he started systematically recording his observations. Three years later, he started writing his results in the form of Sanskrit *shlokas* and made a treatise called *Siddhānta Darpana*, which was completed in 1869 when he was thirty-four. Working in a remote corner of Orissa, far from Cuttack the only town with some semblance of modern

education then, he had no option but to keep the manuscript written on palm leaves in Oriya script for thirty years, lying in a corner of his house.

Prof. Mahesh Chandra Nyayaratna, Principal of Sanskrit College Calcutta, was in charge of Sanskrit education of Bengal presidency, which comprised then, the present Bengal, Bihar and Orissa provinces. In one of his official tour, he providentially met Samanta and was greatly impressed with his erudition and scholarship, and probably he introduced him to Prof. Jogesh Chandra Ray of Cuttack College,presently called Ravenshaw College. Later, it was the recommendation [3, 4] of Prof. Nyayaratna which brought him the title of *Mahamahopadhyaya* conferred by the British government in 1893.

Prof. Jogesh Chandra Ray played a key role in the publication of *Siddhānta Darpana* in Devanagiri script from a Calcutta press in 1899 with the financial support from the kings of Athmalik and Mayurbhanja. It must be noted that the scholarly introduction of fifty six pages in English therein by Prof. Ray[5], formed the window through which the outside world could get a glimpse of the valuable treasure contained in this monumental work in Sanskrit verses, which was hardly accessible.

Samanta Chandra Sekhar, although belonged to a royal family, had to face a lot of hardships to maintain his large family consisting of six daughters, five sons and a large number of hereditary servants. He had a fiefdom of two villages and a small amount of land out of which he had annual income of Rs.500/-, and 1000 maund of paddy. Six months before his death, the government granted him an allowance of Rs.50/- per month. The king Natabar Singh was extremely envious of him for his popularity and put all kinds of hurdles on his way.

He was a very religious person. A large part of his daily life was devoted to prayer, worship and meditation. He breathed his last at Puri on *Jyesth Krishna Dwadāshi*, the 11th June, 1904.

2.2 Association with Jogesh Chandra Ray

Jogesh Chandra Ray was professor of physical sciences in Ravenshaw college, Cuttack in 1893, when he happened to meet Chandra Sekhar during a short visit of the latter to the capital city of Orissa. Although he had no english education and was a simple villager, and Ray had the highest qualification in modern education and also occupying a high position then in academic sphere, it is the love of knowledge which brought them together. This happened only after Chandra Sekhar passed in several severe tests posed by Ray and his english educated colleagues, who were quite sceptical of his ability as an astronomer. In one of the tests, they asked him to find out the distance between Mars and Venus visible in the western sky then, by any improvised instrument. Chandra Sekhar had acquired unbelievable skill in astronomical observations, fabrication of precision instruments and computation of celestial events. On this occasion he did not have any of his instruments with him. How he faced this situation and came out with flying colours is described [5] by Ray himself: "After a moment's pause he made his *Mana Yantra* out of a stick 42 digits

long, attaching a cross piece of 4.5 digits to one end. The trigonometrical functions of sines and cosines were all committed to his memory. The necessary calculations were mentally made, and the instrument was ready in a few minutes". Then of course he came out with the right answer of six degrees.

Although telescope was in use in Europe since the early seventeenth century, Chandra Sekhar had not seen it until he met Ray. He was a fully naked eye astronomer. In this context he had to appear in another test. Ray had a three-inch telescope which he adjusted with magnifying power 80 and offered him to observe the planets through it. This episode[5] has been described by Ray: "The keen delight with which he looked at the varied and picturesque appearance of the Moon, absorbing him for sometime, can better be imagined than described. When the novelty of the aspect had abated a little, he wanted to know the magnifying power. He was told to find it out for himself if he could. The question is itself puzzling, and I did not expect any answer. But he startled me by saying that the instrument magnified about one hundred diameters. He had measured the enlarged image of the Moon as seen through the telescope and had compared it with apparent diameter well known to him".

After such tests and wide ranging discussions on astronomy, Ray was convinced that Chandra Sekhar was a rare genius of extraordinary merit and took interest in his astronomical work *Siddhānta Darpana* written in Sanskrit with Oriya script on palm leaf, by volunteering to shoulder the responsibility for its publication. He contacted publishers in Calcutta, and himself took the charge of editing the book and writing an introduction also. Ray was not himself very proficient in Oriya script and language. He got it rewritten in Bengali script and sent it to Calcutta in November 1884, where it was printed in Devanagari script in Girish Vidyaratna Press in May 1898. The proof correction had taken four years which was accomplished by both Ray and Samanta with the help of Rajballav Mishra a disciple of Samanta and his own son, who were noted Sanskrit scholars with familiarity in Devnagri script. The cost of Rs.1250/ was met by the generous contributions of Kings of Athmullick and Mayurbhanja. Thus the last *siddhānta* of Ancient Indian Astronomy saw the light of the day by the selfless dedication of the humanist and scholar Prof. Jogesh Chandra Ray.

2.3 Impact on contemporary society

Swami Vivekananda has identified religion to be the soul of India. Religion and religious practices are quite central to the life of a Hindu. Thus an almanac is a household need of every Hindu family according to which different religious rites, observance of various festivals, marriages and *shrāddha* etc are conducted through out the year. Almanac acts as regulator and preserver of social life. A notable feature of the 19th century society in our country was severe confusion regarding the correctness of almanacs which were being followed then. No two current almanacs predict the same time for the occurrence of various celestial events. The traditional astronomy grown on Indian soil for millennia had to clash with the European astronomy as an inevitability of the foreign rule.The principal question was which almanac has to be

followed. The orthodox elements in the Hindu society were too dogmatic to believe that ancient *sidhāntas* could have error and needed corrections.They could not accept the foreign nautical almanac to be sacred and divine enough to be followed in conduction of rituals. The social preference was in favour of indigenous correction, if any, to be developed by pundits uncontaminated by foreign education.

In the nineteenth century Orissa, during the advent of Chandra Sekhar there was a great need for a better almanac for the Jagannath temple of Puri and also for the entire state. Up to that period, Orissa did not have an almanac indigenously made in the state and people were using Bengali almanac based on the *Bhasvatikaran* of Shatananda, a noted astronomer of eleventh century from Puri. By 1868, Chandra Sekhar was about to complete the writing of *Siddhānta Darpana* and his name and fame as an astronomer was widely spread in Orissa. People from different parts of the state were going to Khandapara and taking his help in the preparation of horoscope. This was a turbulent period in Orissa history when fierce movement had been launched for the preservation of Oriya language and culture spear-headed by Gouri Shankar Ray, Fakirmohan Senapati, Radhanath Ray and others. Gouri Shankar, founder and editor of the first Oriya newspaper *Utkal Dipikā*, was taking steps to prepare an Oriya almanac. There was a popular urge in favour of adopting an almanac made by Chandra Sekhar based on *Siddhānta Darpana.* However its superiority over the Bengali almanac has to be established before it has popular acceptance. The solar eclipse which occurred on August 18, 1868 provided the golden opportunity for this acid test[6] which was keenly observed with eagerness through out the state. Gouri Shankar at Cuttack, and Chandra Sekhar at Khandpara watched the eclipse with European clock in hand. As the clock went ticking down, it was found that the prediction of the almanac based on *Siddhānta Darpana* was much closure to the actual occurrence than that of Bengali almanac which was way behind. This result was duly proclaimed in the *Utkal Dipikā* in its August 22issue, 1868. Since then the general public spontaneously adopted the former almanac with enthusiasm and reverence. Soon after Gajapati king of Puri, as a mark of honour and recognition, conferred [7] on Samanta the title "*Harichandan Mohapatra*" in 1870. He further convened a national conference in 1876 at Puri, inviting sanskrit scholars and astronomers from important centres like Varanasi and Ujaini etc., to prescribe an almanac for Jagannath temple. The prescriptions of *Siddhānta Darpana* was unanimously accepted by the conference for the regulation of rites and worship of Lord Jagannath which has been continuing since then. Thus it may be said that the work of Samanta has implicitly contributed in a major way to the resurgence of Oriya nationalistic spirit, eventually culminating in the creation of Orissa state in 1936, fulfilling a long cherished aspiration of the people.

2.4 Samanta as a man

Readers will be curious to know what type of person Samanta was? It will suffice here to relate an event [7, 8] of his life, which brings out clearly his character and

personality as a man. The Viceroy and Governor General of India Lansdown, had invited Samanta to be present at Calcutta on 20th August 1893 to honour him by conferring the title "*Mahamahopadhayaya*". Samanta was a very spiritual and pious person who used to devote four hours daily to worship and prayer. He informed the office of the Viceroy, regretting his inability to come to Calcutta, as long absence from home would hamper his devotional practice and scientific pursuit. This unparallel incident shows the courage of conviction and the values Samanta held in his life, and tells volume about his character and personality. However, rather than taking offense at such conduct, the Viceroy ordered his commissioner Mr.Cook at Cuttack, to organise there the same award function called *Durbar*, about a month later on 28th September, to suit the convenience of Samanta.

Natabar Singh Mardaraj, the nephew of Samanta was the king of Khandapara in this period. He was all the time consumed with envy and jealousy at the popularity of Samanta, and had been putting all kinds of hurdles on his path. When he came to know of this invitation, he hatched a conspiracy to prevent Samanta from attending this function. However Rajballav Mishra, one of the disciples of Samanta, drew attention of Mr. Cook to this plot of the king, there upon he decided to arrest the king. Hearing this, the king got frightened and made all arrangements for the journey of Samanta to Cuttack. Finally Samanta accompanied by one of his sons travelled to Cuttack by boat via the river Mahanadi, and reached the village Jobra in the outskirts of the city, and rested in the boat for the day. As per his almanac, this day was 27th September. In the afternoon at about 1 pm, he heard repeated firing of cannons and crackers, and found the king of Athgarh returning in great pomp and ceremony in a procession. He apprehended that the *durbar* might have been over. He got perplexed and hastily moved to the commissioner's house and met him there. Mr. Cook got extremely angry and asked him why he could not be present in the *durbar*. By that time, Samanta had realised that the day was really 28th and his almanac was showing 27th due to a printing error. With great humility, he could convince the commissioner the reason of his lapse and got his pardon. Then he prayed to the Commissioner: "Sir, I understand, arrest warrant is being issued for my king. The award and the decoration will be of no avail to me if the king is arrested. I do not need all these honours. Be kind and gracious to my king and withhold the warrant." Without paying much heed, Mr.Cook left asking Samanta to meet him the next day. On the following day when Samanta met Mr.Cook, he implored him repeating the same prayer of yesterday. Finally Mr.Cook agreed to withhold the warrant for that day. Then he subjected Samanta to a test. Pointing to the distant *Saptasajya* mountain, Mr. Cook asked him to find out its height. Unfortunately Samanta had left his *Mana Yantra* in the boat which was procured by his son hastily and then he measured the height to be 1178 cubit and 16 fingers. Mr. Cook immediately consulted the atlas from his library, and found that, this value was quite close to the actual. Being overwhelmed with happiness he embraced Samanta and showered many praises over him and cancelled his order of arrest warrant. He organised the *durbar* seven days later on 5th October 1893, and conferred the title "*Mahamohapadhyaya*", on behalf

of the Viceroy. This episode in the life of Samanta, clearly shows what a great and noble person he was.

2.5 Samanta as a scientist

Samanta as a scientist was endowed with similar frame of mind and spirit generally found in great scientists of the world. In this section, we will not evaluate his contributions to astronomy, but highlight only his approach, philosophy and the passion that characterize his life-long pursuit of science. It is unfortunate that, many people in Orissa regard him more as an astrologer than an astronomer, although he truly belongs to the same class of astronomer as Āryabhata, Varāhamihira, Brahmagupta and Bhāskara. Pressed by the ignorant public of his time, he was forced to make horoscopes which is normally regarded as astrological activity, but in reality, it is an accurate record keeping of the time of the birth, and the positions of the planets and constellations. Since the early days, astronomy as a branch of science distinct from astrology, was beyond the comprehension of the common man. So the general perception about Samanta as an astrologer wrongly persists even till today.

Whitehead had said: " The essential discovery of modern science was the scientific method itself". The essence of this method consists in making hypothesis about the Nature and predicting the quantitative consequences based on it, which could then be tested in experiments. Samanta made his own set of instruments for astronomical observations. He gave a new planetary model of the solar system, developed new methods of calculation, made predictions and verified them through actual observations. In his treatise *Siddhānta Darpana*, he has boldly stated that he has not written anything in it which has not been verified by him through observations. He called it as "*driksiddha*". Thus his scientific method of research was exactly similar as the modern one, although he had no training whatsoever from any institute or individual.

The most important quality in a great scientist is unshakable faith in his ideas which springs from some inner vision. Samanta has exhibited this quality in ample measure from his very childhood. At the age of fifteen, he came to the thundering conclusion that the old sidhantas like *Sūrya Siddhānta* and *Siddhānta Siromani* are erroneous. He did not stop there, but he took it as his life's mission to correct them which he fulfilled with distinction bringing out the new *Siddhānta Darpana.*

However great an original thinker a scientist may be, ultimately his dedication and hard work in translating his ideas into some concrete observable results, puts the seal of success. Mere professing some new ideas counts for little. In this respect, Samanta can be compared with any great genius in the history noted for his devotion. His dedication as a scientist is best described [5] by Prof. Jogesh Chandra Ray: " The constant strain upon his body which had never been strong began to undermine his system. He contracted a disease which has been his constant companion. Dyspepsia with its attendant colic has impaired his health. At times it becomes so painful that he is compelled to break up conversation, roll down on the ground till the attack is over. Full meals, frugal as they are, he has not enjoyed for thirty years and has seldom

permitted himself the indulgence of even half meal twice a day...... Even in the present invalid state he would willingly sit up a whole night if it were for anything connected with his favourite subject."

3 Elements of Ancient Indian Astronomy

Some essential elements of Indian astronomy are presented in this section briefly to acquaint the lay readers with important basics of astronomy to facilitate their appreciation of the contributions of Samanta.

3.1 Model of the sky

The universe around us extends to infinity in all directions. This sky is limitless. However one has to make a model of the sky, which should be finite in order to be able to describe the motion of the heavenly bodies in it. When one looks at the sky standing on the surface of the earth, one finds the stars and planets shining from the inner surface of a large hollow hemisphere. The positions and motions of heavenly bodies can then be conveniently described in a large sphere called *Celestial Sphere* of very large radius with Earth as its centre. This has been taken as a model of the sky.

3.2 Ecliptic and Equinoxes

Aryabhata had mentioned as early as 5th century AD that, Earth is round and it rotates about its own axis from west to east due to which heavenly bodies appear to move from east to west daily. Then one can define the *celestial poles* to be the two diametrically opposite points where axis $p'p$ of Earth's rotation meets the celestial sphere at $P'P$ when extended (see Fig.1). The *celestial equator* QQ' is a great circle whose plane is perpendicular to the celestial polar axis lying in the same plane as the Earth's equatorial plane. The line perpendicular of the plane of the horizon passing through the position of the observer meets the celestial sphere at Z and Z'.

The Sun appears to move round the Earth in the circular path SS' continuously as observed from the Earth. The apparent annual path SS' of the Sun around the Earth is a great circle called *ecliptic*. The plane of the ecliptic is inclined to the plane of the celestial equator by the angles $23^0 26' 21''$ called *obliquity* of the ecliptic and is usually denoted by ϵ. The celestial equator will cross the ecliptic at two points V and A called *Vernal Equinox* and *Automnal Equinox* respectively. The vernal equinox is the point which the Sun passes in its annual motion while going from south to the north, which is also called the first point of the *Aries*

3.3 Navagrahas

In Indian astronomy, there are nine planets but Earth is not one of them while the Sun and the Moon are considered as two planets. The two intersection points of the

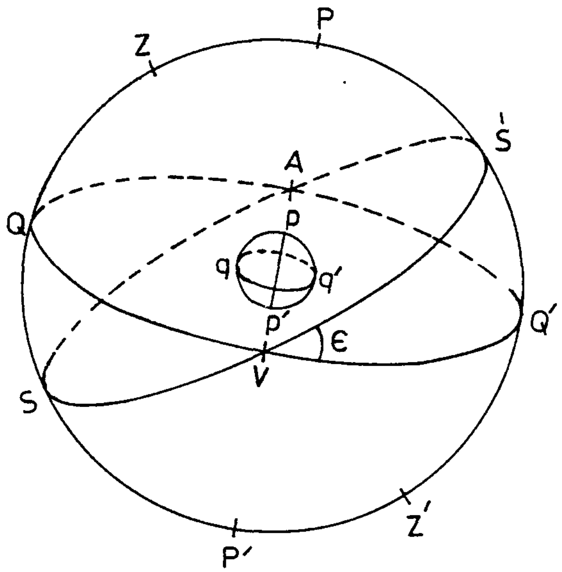


Fig. 1. Ecliptic and Equinoxes

Moon's orbit with the ecliptic are called *Rahu* and *Ketu* which have been taken as two planets. In Western astronomy these are called nodes of the Moon. Thus the visible five planets Mercury, Venus, Mars, Jupiter and Saturn together with Sun, Moon, *Rahu* and *Ketu* constitute the system of Navagrahas(nine planets) in Indian astronomy. The Earth is considered stationary in this system.

3.4 Coordinate system

The angular distance α_1 measured eastward along the ecliptic from the vernal equinox is called the *celestial longitude*, which can vary from 0^o to 360^0. Correspondingly the angular distance of the body from the ecliptic is called *celestial latitude.* In the Indian system, the longitude is measured from a fixed point on the ecliptic called *Mesadi.* This longitude is called sidereal or *nirayana* longitude which will be denoted by α_s. The difference $\delta p = \alpha_1 - \alpha_s$ is called *ayanamsa.*

3.5 Ayana Chalan : the vexing problem

The most vexing problem in astronomy originates due to the precessional motion of the Earth. The axis of the rotation of the earth which passes through its north and south pole is not static, it moves in a small circle once in every 25,800 years. Thus yearly it moves by $50.27''$. Therefore celestial equator keeps on moving backward (retrogrades) along the ecliptic at an annual rate of $50.27''$ as a result the vernal equinox also shifts at the same rate. This phenomenon is called *Ayana Chalan.*

This has given rise to the most vexing problem in astronomy i.e the coordinate system itself is not static. It even varies from one place of observation to another. The celestial longitude of all bodies increases by a constant of $50.27''$ each year. However, the latitude is not affected as the plane of the ecliptic remains fixed. Computation of ayanamsa becomes a major problem. It must be noted that in the theoretical description of a physical system in any theory one uses a fixed coordinate system.

4 Contributions

Chandra Sekhar has made enormous contributions to Indian astronomy in all its aspects. He has attempted to rectify all the errors accumulated for centuries, and in the process, has succeeded in developing a complete system of astronomy based on naked eye observations only. He has given new planetary model, discovered new phenomena, made necessary formulation for astronomical predictions and fabricated ingenious instruments. Here we will only bring out the essential new features of his contributions.

4.1 Siddhānta Darpana

What is a *Siddhānta*? Our ancient scholars most of whom were "rishis", were concerned with wider issues of eternal significance. They investigated the problems following a holistic approach to find a complete and integral picture of the creation, and the place of man in it. Being aware of the magnitude of the problem, Chandra Sekhar has given in the 17th *shloka* of first chapter of *Siddhānta Darpana* the characteristics of *Siddhānta* as

यत्र त्रुट्यादिकालः प्रलयचरमकः खेचराणां प्रचारः
प्रश्नाश्चैवोत्तराणि द्विविधगणितमप्युद्भवो भूतराशेः ।
स्थानं भूभग्रहादेर्ग्रहणखगयुतिज्याधनुष्कर्म्मयन्त्र-
क्षेत्राद्यं गद्यते सद्गणकगणवरैरेष सिद्धान्त उक्तः ॥१७॥

Thus it deals with the time span beginning from the smallest unit of "*Truti*" (0.27434×10^{-6} sec.) to "*Pralaya*" (10^{13} solar years), along with the motion of the celestial bodies comprising their revolution, alignments, occulations, orbits and eclipses etc. with the relevant mathematical tools like arithmetic, algebra, geometry and trigonometry etc.. It has to be also concerned with the question of the origin of the universe. An in-depth study of *Siddhānta Darpana* shows that, this work embodies all these features adequately. This has been written in terms of beautiful Sanskrit *shlokas* following the time honoured Hindu tradition. In addition to being a scientific treatise, it is a fine piece of Sanskrit poetry of considerable literary value.

Siddhānta Darpana is composed of 24 chapters having 2500 *shlokas*, out of which 2284 are Samanta's own compositions and 216 are citations from earlier authors. It is

broadly divided into two parts. viz. *Purbārdha* (first half) and *Uttarārdha* (latter half). The first-half contains 15 chapters grouped into three sections called *adhikar* derived from the word *adhyāya*. The three sections are called *Madhyamādhikāra*, *Spastādhikāra* and *Triprasnādhikāra*. *Madhyamādhikāra* deals with the mean positions of planets (*Madhyamā* means average or mean), obtained by assuming that they move in circular orbits with uniform velocity. In *Spastādhikāra*, the procedure to obtain the true positions (*spasta* refers to true) of the planets from the mean positions by taking into account two corrections called *manda* and *sighra*. *Triprasnādhikāra* deals with the three questions of direction (*dik*), space (*desh*) and time (*kāla*) and discusses the motion in terms of them. The *Uttarārdha* has two sections called *Golādhikāra* and *Kālādhikāra*. While the former deals with the relevant mathematics like trigonometry and geometry etc. the latter mainly describes the different ways of measuring time. The distribution of chapters and *shlokas* with the title of the topic dealt in each chapter is given in Table-1. The contents of *Siddhānta Darpana* look amazing as the achievement of a single mind. Chandra Sekhar has observed, verified and corrected wherever necessary all that was known to the Hindu astronomers for thousands of years. Very often he has gone beyond them to discover new phenomena and to give new formulations and comes out with predictions supposed to remain valid for at least ten thousand years to come.

4.2 Observations

The success in scientific research crucially depends upon how accurately the data can be measured. All progress in science has been possible because of certain individuals who discovered new precision instruments and made skillful measurements with dedication. First we would like to highlight this aspect of the work of Chandra Sekhar, before describing his more fundamental contribution. His fabrication of ingenious instruments will be discussed in Sec.4.7. Because of his untiring zeal for making accurate observations, he spent sleepless nights for years together, afflicting his frail body with dyspepsia and colic, and obtained incredible precession data often comparable with modern data acquired with the help of telescope and other optical instruments. We have chosen three sets of data of Samanta which can be compared with the modern values to illustrate this point. In Table 2, his measurements of the inclination angles of the orbits of the planets to the ecliptic and in Table 3 their sidereal periods in days are compared with the European data[5] of 1899 and recent data[9] of 1994 and also the corresponding ones of *Sūrya Siddhānta* and *Siddhānta Siromani*. It can be seen that his data are far better than the old *Siddhāntas* and agree closely with the modern values.

It is worth noting that inclination angles of the orbits of Venus and Saturn observed by Samanta are even closer to modern values of 1994 than the European values of 1899. In case of the sidereal period of Saturn, while the data of *Sūrya Siddhānta* and *Siddhānta Siromani* are larger than six days compared to modern value, Samanta's result is strikingly close to the latter being within few hours. It must be noted that

Table 1. Summary of the contents of Siddhānta Darpana

Name of Section	Chapter Number	Chapter contents	Number of *Shlokas* in the chapter
Madhyamādhikāra	1	Description of time	55
	2	Description of Bhagan,etc.	25
	3	Mean planet positions	77
	4	Various corrections	57
Spastādhikāra	5	True planet positions	221
	6	Finer corrections	161
Triprasnādhikāra	7	Gnomos,etc.	94
	8	Lunar eclipse	87
	9	Solar eclipse	78
	10	Parilekha description	37
	11	Transit,etc.,of planets	111
	12	Alignments of planets	93
	13	Rising and settings of planets	84
	14	Phases of Moon	67
	15	Description of Mahapata	70
Golādhikāra	16	A set of questions	79
	17	Description of Earth	159
	18	Description of Earth(contd.)	175
	19	The celestial sphere	123
	20	Description of instruments	111
	21	Some deeper questions	249
Kāladhikāra	22	Description of years,etc.	76
	23	prayer to Purusottama	55
	24	Conclusions	156
Total			**2500**

Table 2. Inclinations of the orbits of planets to the ecliptic. The data in the last column is taken from Ref. [9] and the remaining ones from Refs. [5], [10] and [11]. The quantities are in degree minute and second.

Planet	*Sūrya Siddhānta*	*Siddhānta Siromani*	*Siddhānta Darpana*	European value as in 1899	Modern value
	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″
Moon	4 30 -	4 30 -	5 09 -	5 08 48	5 08 33
Mars	1 30 -	1 50 -	1 51 -	1 51 2	1 50 59
Mercury	5 55 -	6 55 -	7 2 -	7 00 08	7 00 18
Jupiter	1 0 -	1 16 -	1 18 -	1 18 41	1 18 18
Venus	2 46 -	3 6 -	3 23 -	3 53 35	3 23 41
Saturn	2 0 -	2 40 -	2 29 -	2 29 40	2 29 10

the data of 1994 have been obtained using the latest telescope and other high sensitive optical instruments. It is indeed amazing how Samanta could achieve such accuracy by naked eye observation.

Table 3. Sidereal period of planets in days. The data in the last column is taken from ref. [9] and the remaining ones from refs. [5], [10] and [11].

Planet	*Sūrya Siddhānta*	*Siddhānta Siromani*	*Siddhānta* Darpana	*European value* as in 1899	Modern value
Sun	365.25875	365.25843	365.25875	365.25637	365.25636
Moon	27.32167	27.32114	27.32167	27.32166	27.3216615
Mars	686.9975	686.9979	686.9857	686.9794	686.97982
Mercury	87.9585	87.9699	87.9701	87.9692	87.969256
Jupiter	4332.3206	4332.2408	4332.6278	4332.5848	4332.589
Venus	224.6985	224.9679	224.7023	224.7007	224.70080
Saturn	10765.773	10765.8152	10759.7605	10759.2197	10759.23
Moon's Nodes	6794.3948	6792.2535	6792.644	6793.270	6793.470

Samanta has measured the eccentricities of the planetary orbits which can be compared with those of Modern astronomy in the case of the Sun and the Moon. With respect to the force centre the angular position of a planet is called the "true anomaly". The eccentric angle of the planet on the auxilliary circle is called the "eccentric anomaly". The difference between the two quantities is the equation of anomaly, the greatest value of which gives a measure of the eccentricity. In Table 4 the greatest equations of the Sun and Moon given by Samanta are compared with

those of *Sūrya Siddhānta* and European values of 1899. Remarkably in the case of Sun, Samanta's value agrees with European value within seconds.

Table 4. Table 4: The greatest equations of Sun and Moon. The data are taken from ref. [5]. The quantities are in degree minute and second.

Celestial Body	*Sūrya Siddhānta*	*Siddhānta Darpana*	Western astronomy as in 1899
	° ′ ″	° ′ ″	° ′ ″
Sun	2 10 31	1 55 33	1 55 19
Moon	5 2 46	5 1 10	6 3 41

4.3 New Planetary Model

A major contribution to theoretical Astronomy of Samanta is his new planetary model of solar system which is different from those of his predecessors in India. Although he believed like them the Earth to be stationary and the planets move around it, yet his model is quite different from the traditional one adopted before. In his new model, the Earth is considered stationary as usual, however the Sun acquires a special position. The planets like Mercury, Venus, Mars, Jupiter and Saturn revolve round the Sun, and the Sun moves around the Earth together with these companions. Thus in this model, the planets have heliocentric motion, and therefore, it is partly heliocentric and partly geocentric. The profile of this model is presented in Fig.2. The central idea of this model has been presented by Samanta in the form of the following *shlokas* of *Siddhānta Darpana* (S.D.Ch. V. *Shlokas* 6,7 and 17).

तत्र मध्यममार्त्तण्डः परितो मण्डलं भुवः ।
भ्रमन् ताराखेचराणां कक्षामध्यस्थ उच्यते ॥६॥
तं भ्रमन्तो महीजाद्यास्तत्सङ्गेन भुवं पुनः ।
परिक्रामन्ति यत्तस्मात् स प्रोक्तः सर्व्वकर्षकः ॥७॥
मन्दापकर्षणं हित्वा सदार्कात् समदूरगाः ।
यान्ति ताराग्रहाः प्राचीं भचक्रमनुलक्षते ॥१७॥

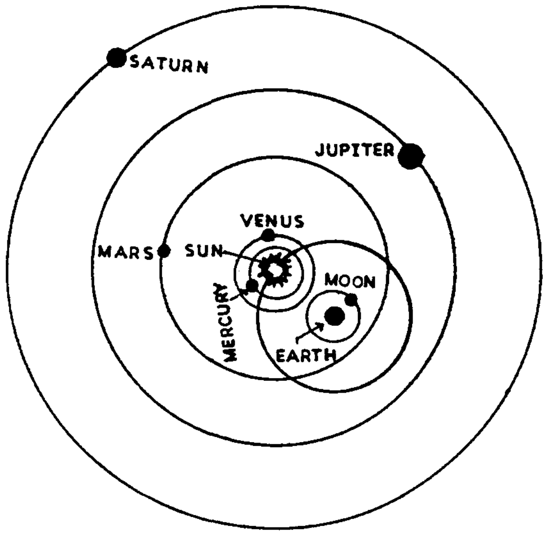


Fig. 2. Planetary Model

The orbits shown in Fig. 2 are circular which corresponds to the mean motion of the planets. The *manda* and *sighra* corrections when applied, will change them to ellipse-like ones. SCS had the visualisation of such orbits as is evident from the following statement of J. C. Ray "But where could he get the theory of planets describing ovals round the Sun? It is not imported from the West, but is a direct corollary from the elements of the planets themselves. For, if we plot the calculated places of planet with respect to the Sun, the former will be found to describe something like an oval round the latter."

Incidentally an identical model of the solar system was proposed by Tycho Brahe in 16th century in Europe. Recently, pioneering work [12] by Ram Subramanyam, Srinivas and Sriram has brought to light that a similar model of planetary system was given by Nilkantha of Kerala school in 1500 AD.

4.4 Original discovery in Moon's motion

Samanta has made original discovery in the motion of the Moon. The three corrections measured by him are *Tungantar*(Evection), *Pakhika* (variation) and *Digmsa*(Annual equation) are encapsulated in the following shloka of *Siddhānta Darpana* (S.D.Ch VI *Shloka* 6).

तुङ्गान्तरं पाक्षिकनामधेयं फलं दिगंशाख्यमदस्तुरीयम् ।
क्रमेण वक्ष्यामि निरीक्ष्य यत्नाच्चित्रां गतिं रात्रिपतेश्चिराय ।।६।।

(a) *Tungantar*(evection)

It is the largest of the three corrections which originates due to the change in the position of the apse line (line joining the maximum and minimum distance positions of the Moon from the Earth) in successive lunar months. This perturbation effectively puts the Moon forward or backward from the expected position by a degree. The maximum value [13, 14] of *Tungantar* according to modern astronomy is $1^0 17'$. Chandra Sekhar observed it to be $2^0 40'$. Ray [5] has resolved this apparent discrepancy of Samanta's value from the modern value. He has pointed out: "The amount of greatest equation of Moon is $6^o 18'$ and maximum eviction $1^0 20'$, making the total of $7^0 38'$. Chandra Sekhar has $5^0 1^0$ as the greatest equation and $2^0 40'$ as the greatest *tungāntar* making the total $7^0 41'$". Therefore result of Chandrasekhar's observation is surprisingly in close agreement with the modern value.

(b) *Pākshika* (Variation)

This irregularity in the motion of the Moon occurs due to the following. During the bright fortnight of the lunar months, the Moon moves away from the Sun, hence the attractive gravitational force of the Sun on it retards its motion. During the dark fortnight, the effect is opposite and the Moon is accelerated. According to modern astronomy, this causes a maximum shift in the position of the Moon by $39' 31''$ Samanta's value of $38' 12''$ is in excellent agreement with it.

(c) *Digamsa*(Annual Equation)

This irregularity originates in the variation of the Sun-Moon distance as the Earth orbits around the Sun in the course of a year. As per modern astronomy the maximum value of this correction is $11' 9''$. Samanta's value of $12'$ is quite close to it.

It is desirable to know if these three irregularities were known to our ancient Indian astronomers and were used in astronomical predictions by them. In this context J.C.Ray notes: "In computing the Moon's place that Chandrasekhar has discovered some original corrections - original in the sense of their having been unknown to the ancient astronomers of our country. It is curious to note that they failed to discover the perturbation, known as Evection which is said to have been detected by Hipparchus about 150 years BC. It is an irregularity which may put the Moon forward or backward over a degree. Pandit Sudhakar Dwivedy informs us in his excellent manual called *Ganak-tarangini* that *Munjalā* (AD 933) had something like "evection" in his *karan* named *Laghumānas*. He appears to have been the oldest Hindu astronomer who detected this irregularity though curiously enough, his successors including Bhāskar left it unnoticed" Even Burgess in his english translation of *Sūrya Siddhānta* says that Hindus did not take notice of evection.

Regarding the second irregularity *Pākhika*(variation), Ray says that this irregularity does not affect the time of an eclipse, and therefore, it is not found in Sanskrit *Siddhāntas*. He adds further that from Dwivedy's *Ganak-Tarangini* it appears that Nityananda in 1639 AD used a correction called *Pākhika*, but it is not clear from the name alone, if it had any connection with "variation". However the latest view on this issue is that of Sengupta [15] who in his translation of *Khandakhādyaka* in 1934 states that "evection" and "variation" were introduced by Munjulā and Bhāskar. But

about the third correction *Digamsa* it can be said without a shadow of doubt, that Chandra Sekhar had discovered it, and it was not known to any Indian astronomers. This is acknowledged in the recent book by Balachandra Rao [16]. In addition, it is fair to state that he is the only astronomer who measured all these three irregularities with utmost accuracy in agreement with modern values and used them in the calculations. Tycho Brahe in Europe was the first western astronomer who has detected and measured all the three irregularities.

4.5 Revolutionary changes in Sun and Moon distances

The distances of Sun and Moon from the Earth are important quantities that should enter into the calculation of astronomical events. In ancient Indian astronomy, they mainly use their ratio rather than absolute values of their distances in the calculation of eclipses and other astronomical events. Thus they use only parallaxes of the planets in all their calculations. They were satisfied with taking the parallax of each planet to be $\frac{1}{15}$th part of its mean daily motion. Thus the Sun's horizontal parallax was taken to be $3'56''$ and that of the Moon $52'42''$. Samanta discovered that these values are too large to make any worthwhile prediction of eclipses which could be correct. He worried over this problem for several years and spent many sleepless nights. Thus dejected, once while he was entering the courtyard of his home, he noticed a beautiful image of the Sun on the wall, formed by the sun rays passing through an aperature in the adjoining fence made up of palm leaves. Exulted to think that he would be able to get the Sun's real diameter and its distance by considering the two similar triangles on the two sides of the aperature, he started measuring the sides. Soon his exultation gave way to despair.

The above problem continued to remain with him for a whole long year without leaving him a single day. In this state of mind, once while reading *Atharv* Ved, he accidentally found in it the diameter of the Sun given as 72000 *yojanas* as against 6500 *yojanas* in *Sūrya Siddhānta.* He took it to be an important clue. The ancient Indian astronomers placed the Sun at a distance of not more than 14 times that of the Moon from the Earth. Samanta hiked this ratio by more than 10 times to 154 which is much closer to the modern value 390. Due to this revolutionary hiking of the distance of the Sun to a more reasonable value, and the accurate measurement of the three irregularities in the motion of the Moon, the accuracy of the prediction of solar and lunar eclipses by Samanta improved dramatically agreeing closely with the observations.

4.6 Calculations of longitudes

Samanta Chandra Sekhar achieved spectacular accuracy in predicting the planetary positions by very accurate calculations of *Nirayana* longitudes. Recently predictions of longitudes of planets as per eight different astronomical texts i.e. *Āryabhatya, Khandakhādyaka, Laghu Mānasa, Sūrya Siddhānta, Siddhānta Siromani, Graha Lāghava,*

Tantra Sangraha and Siddhānta Darpana have been compared with the modern values (generated by a software written in 1980). In case of Siddhānta Darpana, the rms deviation for the longitude of the moon is only 20 minutes, while for all others it is greater than 1.3 degrees. This is essentially due to Samanta's discovery of the anomalies in the motion of the Moon discussed before. Similarly for Jupiter, Siddhānta Darpana predicts a value of 20 minutes only for rms deviation, while all others except Tantra Sangraha give values greater than 2 degrees. A detailed discussion of this investigation can be seen in the article by Ramsubramanian in this volume.

4.7 Innovations in calculation

In modern astronomy, for the successful prediction of astronomical events, one has to know the positions of the planets as function of time most accurately. This requires the solution of nine coupled Newton's Equations involving Gravitational interaction. This is quite formidable even with the use of modern computer. In traditional Indian astronomy, the Equation of Motion is unknown. One devises various phenomenological methods basing on one's own ingenuity, guided by the observation of celestial events. Therefore prediction of their positions is a herculian process. This is usually accomplished in two steps. In the first step, one computes the mean position assuming a mean rate of motion of each planet. For this, one assumes an epoch at the beginning of which all the planets are supposed to have started their revolution called *bhagan*. The mean positions of the planets, on a particular day, are obtained by multiplying the respective rates with the number of *bhagans* completed by them. Then the true positions are obtained by adding several corrections using a phenomenological model called "epicycle model". It is not possible to enter into discussion on this model here due to lack of space. The reader may refer to the recent book by Balachandra Rao[16] in this context.

The traditional astronomical works can be divided into three classes, depending upon their choice of the epoch. *Tantra* and *Karans* choose the beginning of the *Kali Yuga* and some recent date respectively to mark the epoch, while the *Siddhāntas* take the period to be a *Maha Yuga*, which is the sum of the period of four *yugas* amounting to 432×10^4 years. Samanta Chandra Sekhar has taken the epoch from the beginning of the *Kalpa* (1000 *Maha Yugas*). He has calculated the number of sidereal revolutions of the planets during the *Kalpa*.

Samanta had great passion for the accuracy in the calculation. He has given the mean rate of motion (average angular displacement per day) up to ten places in sexagesimal system whereas, earlier *siddhantas* have given these figures to five places at best. In Table 5, we have compared the modern values of these rates in the decimal system, and also given the traditional data converted into decimal system. Samanta has not given the rate of Mercury and Venus, instead he has given the rates of their *sighrochch* in sexagesimal system which he considered more useful for calculation.

Samanta has found various corrections to be added to the mean positions of the planets to obtain their true positions, and accordingly given prescriptions in *Siddhānta*

Table 5. Table 5: Rates of mean motion of the planets per day. The quantities in the upper line in each row in the third and fourth column are in sexagesimal system, and in the corresponding lower lines in decimal system. The modern values are from ref.[9] and those of *Siddhāntas* from refs. [10, 11]. The quantities are in degree, minute and second.

Planet	Modern Value (Lahiri)	Brahmagupta Sripati Bhaskar	Samanta Chandra Sekhar
Sun	0 59 08.2	0 59/8/10/21	59/8/10/24/12/30/4/0/4
		0 59 8.1725	0 59 8.1733912182
Moon	13 10 35.0	13/10/34/53/0	13/10/34/52/03/49/08/02/16/10/11
		13 10 34.8833	13 10 34.8677275173
Mars	0 31 26.5	0/31/26/28/7	0 31 26.5018877228
		0 31 26.4686	
Mercury	4 05 32.4	4/05/32/18/28	⋆
		4 5 32.3077	
Jupiter	0 04 59.1	0/04/59/9/9	0/04/59/05/37/0/36/41/17/01/51
		0 04 59.1525	0 04 59.0936139473
Venus	1.36 07.7	1/36/7/44/35	⋆
		1 36 7.74305	
Saturn	0 02 01.9	0/02/0/22/51	0/02/0/26/55/02/53/21/02/04/54
		0 2 0.380833	0 0 2.448624511
Moon's nodes	-0 03 10.6	0/03/10/48/20	0/03/10/47/40/40/27/11/25/13/30
		0 03 10.8055	0 03 10.7946631769

⋆ Mean of *sighrochcha* of Mercury and Venus are given as $4^0/05'/32''$/16/07/59/43/42/44 and $1^0/36'/07''$/47/57/50/39/32/31/35 respectively.

Darpana for the computation of astronomical prediction, which is supposed to remain valid for ten thousand years. He has recognised that additional finer corrections are necessary to be added from time to time to keep his prescriptions valid for hundred million (one *Arbuda*) years. For the calculation of these additional corrections, he has given as many as 55 tables each containing 50 numbers sometimes given up to five places in sexagesimal system. All these go to show his amazing computational skill and his ability to carry out enormous computation using vast multitude of large numbers without any aid.

For the proper description of a physical system, the choice of the coordinate system plays a crucial role. As noted in section 3.5, the most vexing problem is the continuous change of the co-ordinate of a point because of the precession of the earth's axis called *Ayan Chalan* discussed before. To fix the longitude of the first point of *Aries*

Table 6. *Ayana Chalan* rates from various sources

Sl. No.	Astronomical Work	Annual rate
1	*Sūrya Siddhānta*	54″
2	*Soma Siddhānta*	54″
3	*Sākalya Siddhānta*	54″
4	*Laghu Vashistha*	54″
5	*Parāsara Siddhānta*	52.35″
6	*Aryastha Stika*	46.25″
7	*Munjalā (quoted by Bhāskar)*	59.9″
8	*Bhāsvati*	60″
9	*Grahalāghava*	60″
10	*Siddhānta Darpana*	57.615″

called *Ayanamsa* (see sec. 3), which is the origin in the Indian system one must accurately determine the precessional rate of the Earth. The modern value of this rate is 50.3″ per year. The rates given in different *siddhāntas* including that of *Siddhānta Darpana* are presented in the Table 6 for comparison. It can be seen that, all the rates are substantially off the modern value except that of *Parāsara Siddhānta*, which is apparently close. Ray has extensively discussed this problem and satisfactorily resolved this puzzle. He has pointed out that the Indian astronomers take the sidereal year for calculation of the precessional rate, in contrast to the tropical year taken in the western astronomy. The sidereal year is longer than the tropical year by some minutes during which the Sun advances by 8.4″ seconds. When this correction is taken into account, Samanta's value comes to 49.179″ which is quite close to the modern value, while all others are substantially off. On checking with a current almanac [17], we find that a rate of 57.628″ per year is still in vogue in the calculation. The determination of right *Ayanāmsa* by Samanta contributed substantially to his unprecedented success in astronomical predictions.

Newton had to develop Calculus, a new branch of mathematics to study the motion of the celestial bodies properly. Although Samanta was ignorant of the equation of motion, he had to phenomenologically predict the true positions of the planets without which he could never succed to make reliable prediction of eclipses. Somehow or other he had to invent some mathematical schemes. He had devised a diagramatic or graphical method (*parilekh*) for calculation of eclipses and many other phenomena. In this method, when nature and periodicity of the motion of the heavenly bodies are known, one can simulate the phenomena by constructing geometrical diagrams on the plane surface and use them for computation of dynamical quantities. This method might be akin to the numerical evaluation of integral. Description or mention of this method is not found in any earlier work. A closer investigation of this is surely called for.

Finally we would like to point out two facts of mathematical interest from *Siddhānta Darpana*. Samanta has stated that Bhāskar and other predecessors have used 22/7

as the value of π. But he has found much improved value of π like 3927/1250 and 600/191 and used them in his calculations. His passion for accuracy is clearly evident. He has found a new method of computing the cube root of numbers different from that of Bhāskar.

4.8 Fabrication of ingenious instruments

Chandra Sekhar was a complete scientists in all respects, who gave his own model of planetary system, made measurements, developed methods for calculation and most importantly, fabricated his own instruments. Being located in a remote corner of Orissa, he was not aware of the scientific and technological developments that had already taken place in the West. He had neither an opportunity of seeing any instrument being used by an astronomer, nor any worthwhile guidance from old astronomical texts for method of fabrication. It is remarkable that Maharaja Jaisingh (1688-1743) using his western contact, built a number of obervatories [18] in northern India. His instruments for measurements in these observatories are rather gigantic. In contrast, Chandra Sekhar who worked in astronomy 150 years later, fabricated mostly simple and portable devices relying totally on his own ingenuity, with locally available materials and using them, could measure very high precission data.

Chandra Sekhar has devoted the entire 20th chapter of *Siddhānta Darpana* to give a detailed description of the construction and use of various instruments. In this respect, he is unique compared to his predecessors who hardly mentioned even the instruments they had used. Recently attempt [19, 20] is being made to shed light on the instrumentation in the ancient astronomical works of India. Chandra Sekhar's instruments can be broadly classified into three categories:(i) Instruments for measurement of time, (ii) armilary sphere and (iii) versatile instruments. Chandra Sekhar shares the same passion with modern scientists to measure time as accurately as possible. He has given description of as many as ten different instruments in *Siddhānta Darpana* for measuring time. These include the sun-dial like *Chakra Yantra* (Fig.3), *Chāpa Yantra* (Fig.4), *Golādhāra Yantra* (Fig.5) and water clock (Fig.6). The armilary sphere or *Gola Yantra* is known to have been commonly used by Greek, Arab and Hindu astronomers for measuring the position and motion of planets. Chandra Sekhar innovated it and devised a much improved version capable of measuring the longitude and declination of planets, and thereby could detect their direct and retrograde motion. He has given detailed description of how to construct it with wood and bamboo sticks. A simplified version of it is presented in Fig.7.

Chandra Sekhar's most ingenious instrument is *Mana Yantra* which is a multipurpose device capable of measuring a host of quantities like latitude, altitude, zenith distance, declination of Sun and its position in the Zodiac, angular separation between celestial bodies, and height and distance of distant mountain. It consists of a staff to which is attached a cross-piece in the form of "T". Twenty four stairs have been cut into the cross piece making 4^o angle each, and further each stair has been further subdivided at half degree angle. A simplified version of it is presented in Fig.(8). He

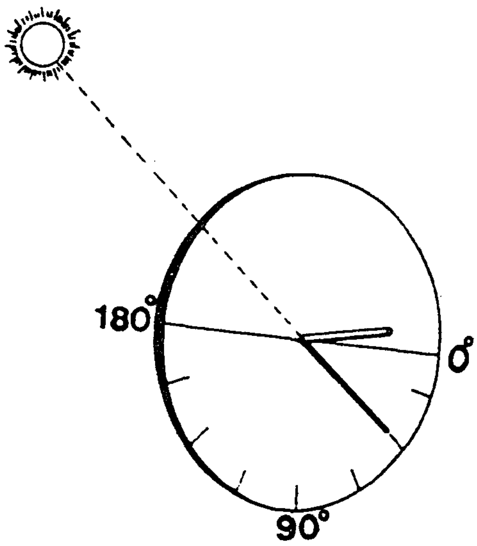


Fig. 3. *Chakra Yantra* for measurement of time

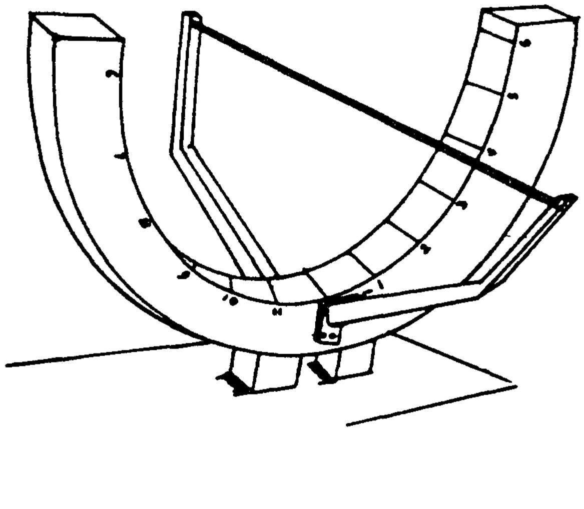


Fig. 4. *Chapa Yantra* for measurement of time

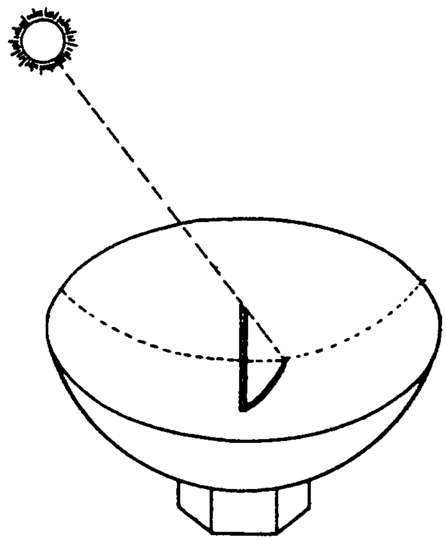


Fig. 5. *Golardha Yantra* for measurement of time

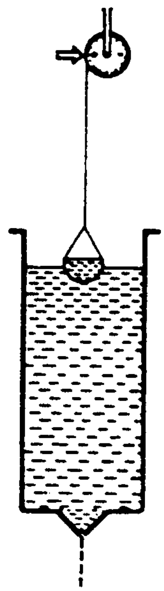


Fig. 6. *Swayambha Yantra*- a water clock for measurement of time

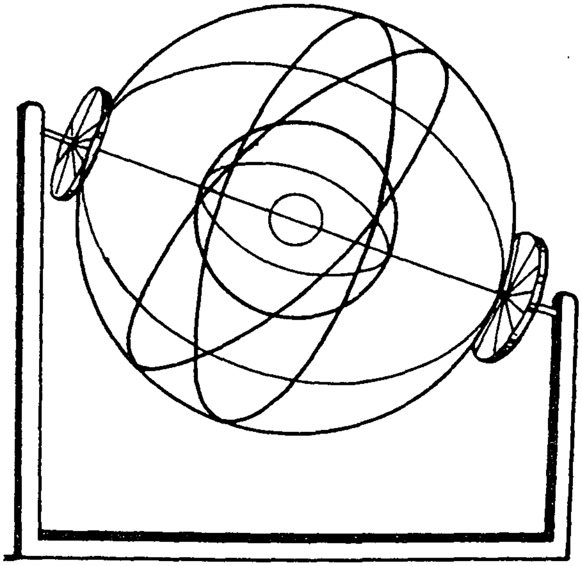


Fig. 7. *Gola Yantra* for measurement of planetary position

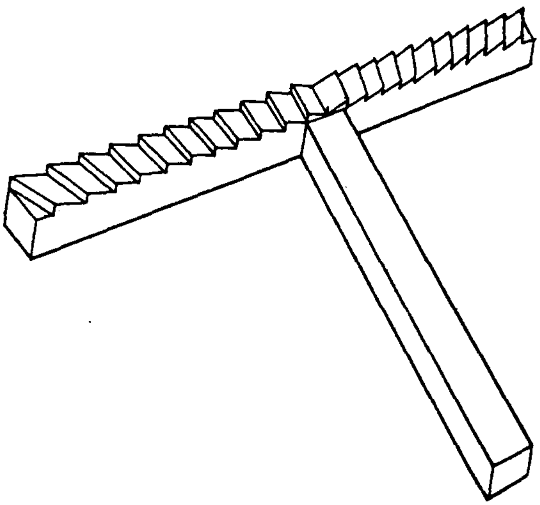


Fig. 8. *Mana Yantra*- a versatile instrument for measurement of various astronomical parameters

had came out in flying colours in many tests posed to him by sceptics with the help of *Mana Yantra*.

Some of the instruments fabricated and used by Samanta have been preserved in Orissa State Museum at Bhubaneswar. Recently Regional Science Centre, Bhubaneswar has fabricated [21] many of these instruments and has put on display. Undoubtedly, Samanta's instruments are quite crude by today's standard, but using them he could measure astronomical data by naked eye observations in close agreement with the modern values. This astonishing feat is certainly due to the unbelievable experimental skill he had acquired by shear dedication and perseverance.

5 Recognition and Awards

(a) Nature

Samanta Chandra Sekhar has got the best recognition and compliments for his work from abroad. In Western astronomy, Tycho Brahe occupies a position in the company of the all-time greats like Copernicus, Galileo and Kepler et al. Can one compare Samanta with Tycho Brahe ?

An extensive report on *Siddhānta Darpana* was published by the international journal "Nature" in its March 9th issue of volume **59, 1899** with the title "A modern Tycho". In the final analysis it commented: "Prof. Ray compares the author very properly to Tycho. But we should imagine him to be greater". This is undoubtedly a unique honour to an Indian scientist from the West.

(b) Knowledge

Samanta Chandra Sekhar has shown that it is possible to build a complete system of Astronomy based on naked eye observation with predictive potential matched with the Modern Astronomy. This has been recognised and acclaimed in the west. To this effect the international journal "Knowledge" wrote in its report [22] on *Siddhānta Darpana* in its Jan-Dec. issue of Vol.XXII, 1899: "It is a complete system of astronomy founded on naked eye observation only. The work is of importance and interest to us westerners also. It demonstrates the degree of accuracy which was possible in astronomical observation before the invention of telescope."

(c) Award by Govt. of India

The Viceroy and the Governer General of India Lansdown, honoured [7, 5] Samanta by conferring the title "*Mahamahopadhyaya*" in 1893.

(d) Award by Gajapati King of Puri

In 1870, the Gajapati King of Puri conferred [7, 8] on Samanta the title of Harichandan Mohapatra in recognition of his monumental work. A conference of Sanskrit scholars held at Puri in 1876 accepted the astronomical prescriptions of *Siddhānta Darpana* for regulation of rites and worship at the temple of Lord Jagannath, which has been continuing since then.

6 Literal truth of Samanta's planetary model

The major contribution of Samanta to Astronomy is his planetary model of the solar system. It is a geocentric model in which the Earth is supposed to be stationary and the Sun, Moon and other planets move around it. The novel feature is that the planets Mercury, Venus, Mars, Jupiter and Saturn go around the Sun and the Sun together with these companions move around the Earth. Thus it is partly heliocentric. It is different from those of his predecessors in India. This model is the very foundation stone of his entire edifice of astronomical work, which he used for all his calculation and predictions. This is in sharp contrast to the modern and all-time accepted model, which is fully heliocentric with the Sun at the centre and the Earth and other planets revolving around it. Needles to say that this model originally proposed by Copernicus in a rudimentary form, was subsequently improved to its perfection by Kepler, Galileo and Newton, and has been universally accepted, being supported by innumerable modern scientific experimentation with satellites, space telescope etc. The question then arises: Is Samanta's Planetary model wrong ? This important question has raised its head in the minds of his friends, admirers and public at large, since the days of Samanta. The inestimable love and respect with which this illustrious son of Orissa is held by its people, makes the matter more poignant lending it an emotional aura. What is the real truth ? The aim of this section is to provide an answer to this question.

In this context the following three points deserve our serious consideration.

1. Samanta Chandra Sekhar was obsessed with the above question throughout his life. He was aware of the fact that his model was diametrically opposite to the western heliocentric model. The latter model is not the creation of a single person, but the well accepted view of the whole western world then. The political and social milieu of Samanta's time must be considered. India was then a part of the British empire which covered so much of the world that the Sun did not set in its territory. Being the harbinger of the scientific revolution in the sixteenth/seventeenth century, England was the leader of the subsequent growth in science in the following centuries. Yet, Samant challenged the heliocentric model and unwaveringly stuck to his model proclaiming its infailability. In Siddhānta Darpana he has declared that he has not written anything in it which he has not observed i.e. *Driksiddha*. It implies that his model is the result of direct observation, not based on any postulate or hypothesis. He has devoted a full chapter i.e. the 17th chapter in *Siddhānta Darpana*, comprising 161 *shlokas* to prove that his arguments in support of his model are irrefutable. In the last *shloka* of *Siddhānta Darpana*, he has predicted that this book will act as a lion who will succeed in trampling and fully demolishing the tuskers i.e. the English pundits who professed the Earth to be moving in the cosmos although in reality it is static.
2. It is amazing to note that in the 16th century, Tycho Brahe in Europe, had proposed exactly the same model as that of Samanta. Recently, it has come to light that Nilakantha of Kerala School of Astronomy had also proposed the same

model in 1500 AD about 50 years before Tycho Brahe. Thus three astronomers have arrived at the same model independently, living in widely separated parts of the world at different periods of time spanning around 400 years.

3. Samanta made all his predictions based on his planetary model. It is indeed intersting to note that his predictions are astonishingly close to the actual observations.

Without any reservation, one can say that the three astronomers Nilakantha, Tycho and Samanta have been led into the same planetary model by their own observations of the positions and motion of the planets rather than by speculation. Samanta has emphatically recorded it in *Siddhānta Darpana* as pointed before. The most important predictions in Astronomy are those about the occurrences of the solar and lunar eclipses. In this respect, Samanta's predictions are far better than those of his predecessors, and accurate enough, to warrant confidence in his model.

On the face of the above overwhelming supports, one is forced to conclude that the planetary model of Samanta must be correct. Now the question arises, if Samanta's model is really true, then what about the modern heliocentric model which has been universally accepted ? In the remaining part of this section we will address this issue.

Every object in the universe is in perpetual motion. No object is at rest. Starting from the atoms and molecules and their constituents electrons, protons and neutrons upto gygantic astronomical objects like planets, stars and galaxies are in fact constantly moving. A piece of stone lying on the surface of the Earth is normally considered to be at rest. In reality, it has several kinds of motion which it executes simultaneously. At microscopic level, the electrons, protons and neutrons which constitute the atoms and molecules of this piece of stone move with speed close to the speed of light. As a bulk, it undergoes all the motion which the Earth perpetually executes. It must be noted that the Earth has five kinds of motion operative simultaneously. Due to the rotational motion around its axis, a point on the equator moves at 1040 miles/hour. The Earth revolves around the Sun at an average speed of 18.5 miles/sec. The Earth also undergoes precessional motion like a rotating top. It takes 25800 years to complete a cycle. The Sun is not stationary. Together with its planets, it moves towards the constellation Hercules at a speed of 12 miles/sec. Our Sun is a star in the galaxy Milky Way. This galaxy rotates at a speed of 155 miles/sec. Moving at this speed, the solar system completes one revolution around the centre of the galaxy at about 200 million years. Finally the solar system moves with the Milky Way as the entire galaxy travels through the universe. This general scenario must be kept in mind while ascertaining the truth of any planetary model.

Thus, both the Sun and the Earth are in constant motion. However, the concept that a body is static has sense only when we refer its state with respect to another body, i.e. it has to be only relative. Consider two objects A and B moving with velocity 5 miles/sec and 10 miles/sec respectively in the same direction East to West. An observer sitting on A will see A as static and B moving towards West with velocity 5 miles/sec. However, an observer sitting on B will see it to be static, and A moving with 5 miles/sec towards East. Both the observers can quarrel insisting each is right. If we ask which observer is correct, the answer obviously is both are correct. Samanta

sitting on Earth made all the observations with respect to the Earth and saw the Earth to be stationary and the Sun going around it. In the heliocentric model, one makes all observations with respect to the Sun and sees the Sun as static and the Earth going around it. Our observations are dependent upon the position with respect to which we make the observation. In the language of physics, it is dependent on the frame of reference or co-ordinate system. Thus both the Samanta's Planetary model and the heliocentric models are correct. Why then is the popular mind there is an impression that Samanta's model is incorrect ? It is not only an impression, even taken as a fact. What then is the mystery ? What is the truth of the matter ? In the following, we feel the mystery is convincingly resolved.

Consider a merry-go-round with the children sitting on the chairs hanging from its circular rim. During the play, the children move in a circular orbit around the axis fixed on the ground at the centre. An observer named A, standing at the centre will observe the children moving in a perfect circle. He will have a clear view of every child also. Consider another observer named B, standing at a distance from the merry-go-round observing the same. He will not see the children moving on a perfect circle. He will rather see the path to be an ellipse. Let B move further away and observe the play. He will find the path becoming more and more elliptical, and finally becoming a straight line as he moves sufficiently away from the merry-go-round. At every position, the observations made by B are undoubtedly correct, although they do no agree with those of A. The observations reported by both A and B are correct and represent two different descriptions of a common event. A, being at the centre of the merry-go-round, is in a convenient position to observe the details of the movement of every child in the circular path, while B stationed at a distance from the centre would observe it somewhat hazy and distorted due to his inconvenient position. However, B with his data can also describe the event and predict correctly the motion of every child and will be able to say when each will cross a given point. Therefore Samanta could predict astronomical events, in particular the solar and lunar eclipses, with precision comparable with that of modern heliocentric model. It is only in the above sense Samanta's model is deficient and the heliocentric model gives a clearer picture.

7 Tycho of India

Ray[5] has called Chandra Sekhar as the veritable Tycho of India which has been endorsed by the prestigious international journal "Nature". He has drawn a great deal of parallelism between the lives of these two great personalities. Like Tycho, Chandra Sekhar was born in a noble family which was ruling a state as sovereign for a long period. Tycho's early education was in Latin while that of Chandra Sekhar was in Sanskrit. The relation of Sanskrit to India is quite analogous to that of Latin to Europe. Tycho was a scholar in Latin and could compose verses in it like Samanta in Sanskrit. Both were introduced to astronomy at early age by their respective uncles. While Chandra Sekhar followed the text of Bhāskara, Tycho followed that of Copernicus. The family of Tycho had felt disgraced at his choice to become an astronomer.

Similar was the predicament of the king Natabar Singh, nephew of Chandra Sekhar.

Tycho had before him the Copernican theory of planetary motion with the Sun stationary, and the planets revolving around it. Chandra Sekhar had similar scenario before him with the diurnal motion propounded by Āryabhata, and more importantly, the contemporary Geography being taught in schools emphasizing the glory of heliocentric model. Amazingly, both declined the new model precisely on the same ground.

Both Tycho and Chandra Sekhar were religous to the very core of their beings. One must remember that, although Copernicus had put forward his theory of heliocentric motion, it was not accepted by the Church and the fraternity of the clergy. Tycho, being a highly religious person would not antagonise the church by holding a view not acceptable to it. Chandra Sekhar was in the similar predicament. Being a staunch Hindu and a religious person to the backbone, he could not disbelieve the *Shāstras*. The parallelism between these two personalities comes to its climax in their proposition of the identical planetary model for the solar system with the heliocentric motion for the planets and the Earth considered as stationary. Both are credited with making high precission observations with naked eye.

The similarity of the lives of the two persons extends so far only. Now we focus on the divergences of their fortune. Tycho had the of university education, and enjoyed the royal patronage in the form of the friendship of Fridrich II of Denmark who gave him an estate in Norway, a pension of 400 pound a year for life, and land for a large observatory with a grant of 20,000 pound to build it. With such help, Tycho built the finest observatory Uraniborg in the world, and made observations that are considered the most accurate ever made before the invention of telescope. Philosophers, kings and statesmen used to visit his observatory and dine with him. In contrast, Chandra Sekhar had to put up with severe royal antagonism, mockery and sneers from his equals, lack of encouragement and indifference of the society to his work, finally and quite importantly the gruelling poverty. Thus his life is the saga of the triumph of the human spirit over the antagonistic external world with its complex and varied social, political and historic forces.

8 Conclusion

From the brief account of the life and work of Samanta Chandra Sekhar presented above, it can be concluded that he could achieve his mission of correcting the errors that had accumulated in Indian astronomy for about two millennia, and founded a complete system of Astronomy, useful and usable for the description and prediction of astronomical events. This is self evident from the continuing use of the almanac based on *Siddhānta Darpana* in the Jagannath temple of Puri and also whole of Orissa, since the days of Samanta till date. His prescriptions have stood the test of time. It is fare to state that his illustrious predecessors had developed a system of Astronomy which was

undoubtedly invaluable, but it lacked the ability for quantitative predictions. Samanta built a new edifice over this foundation and could reach the goal fixed by *Rishis* in the early Vedic ages. Thus, he fulfilled the aspirations and dreams entertained by them in the distant past and sustained by successive astronomers over millennia. As discussed elaborately before, we would like to emphasize here in unequivocal term that, his planetary model with stationary Earth and heliocentric motion of the planets is not incorrect scientifically. It is a true description of the astronomical events with respect to the Earth as the origin. It is equivalent to the modern fully heliocentric model where the Sun is taken as the origin. He has truly accomplished a historic mission and is the veritable Tycho Brahe of India. The generous comment of "Nature" that he is greater than Tycho should gladden the heart of the people of our country and fill them with pride.

In the field of naked eye Astronomy, Samanta Chandra Sekhar occupies a unique position. With the invention of modern scientific instruments, the quality and the nature of astronomical data underwent a sea of change after sixteenth century. However, working in the 19th century, Samanta stood on his ground firmly by sheer dedication and persiverence, and finally succeeded in overcoming such discomfitures. In view of the fact that the quality of data obtained by him through naked eye observations, which are comparable to those of the modern astronomy based on telescope and other optical instruments, and also the predictive potential of his work expected to remain valid for thousands of years to come, it may be fare to state that he was probably the greatest naked eye astronomer of the world. In fact, he reached the limit of accuracy possible through the naked eye observation. The endorsement to this effect: " It demonstrates the degree of accuracy which was possible in astronomical observations before the invention of telescope" by the international journal "Knowledge" quoted earlier is too exulting for us to believe. In view of his unique contribution and the historic role he played in bringing the subject to its perfection, it will be fare to accord him the position in Ancient Indian Astronomy at par with Āryabhata, Varāhmihira, Brahmagupta and Bhāskara.

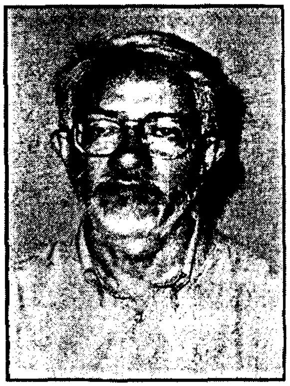
Unfortunately due to various historical and geographical reasons, Samanta's true position in Ancient Indian Astronomy has not been properly ascertained so far. This is because he is scarcely known outside the State of Orissa, although he lived and worked fairly recently in the latter half of nineteenth century spilling over even couple of years into the twentieth century. This has probably happened due to his advent in a highly decadent period of Orissa history commencing with its loss of independence in 1568. Thus he lived and worked during a period which was about 300 years after it lost its imperial glory and pre-eminent position in Indian subcontinent. Although Orissa came under British rule in 1803, it continued to remain in virtual darkness during the life time of Samanta, being deprived of the advantage of modern education. It is a matter of great satisfaction that belatedly the work of Samanta Chandra Sekhar has drawn attention of the scientific community of our country and the process of his recognition by them is well in progress. Kochar and Narlikar have acknowledged his contributions in glowing terms in their two books [23, 24] published in the last decade.

Recently Balachandra Rao[16] has given due recognition to the work of Samanta in his new book on Indian Astronomy. In the major national conferences [25–28] on Indian Astronomy, Samanta Chandra Sekhar and his contributions have been widely discussed as a central theme in recent years. Recently a long-felt need of scholars and public at large, has been fulfilled by Upadhyaya [29] through his translation of *Siddhānta Darpana* into Hindi and English supplemented with commentary. It is a matter of great satisfaction that in honour of Samanta Chandra Sekhar the Government of India has just released on 11th June, 2001 a commemorative stamp bearing his image and name. Way back in 1976, it was translated into Oriya by Sastri [30].

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Samanta Chandra Sekhar – His Relevance in Modern Times

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All of us are familiar with the story of Samanta Chandra Sekhar's exploits in the science of Astronomy. It is unimportant to recount the fact that he made significant discoveries, which were definite improvement over the old *siddhāntas*. That he could come so close to the modern values with his most primitive equipments is certainly remarkable. No wonder C.R.F. Maunder amazed at the " Astronomy without Telescope" which came close to the modern values. Indeed the phenomenon of Chandra Sekhar is a bit of a surprise. We intend to make an evaluation of his work particularly in a context of what we know today in astronomy.

One can raise three questions in this context. First question is, after all Chandra Sekhar rediscovered, under handicap, which had already been discovered at least three centuries earlier in Europe. So why should one be seriously interested in the study of an enormous volume of work written in an obscure language and style, substance of which are available in much better accessible forms and are definite improvements over what is contained in the monumental work called "*Siddhānta Darpana*"? Is it that we deride the achievements of Samanta as pointless exercise in futility? or is it the handicap and poverty of Samanta that should move us out of pity to look at his work? Or is there anything worthwhile or relevant for a modern scientist to learn from? Is it that we are telling that it was unfortunate that he was not born three centuries earlier or is it his bad luck that he had no access to modern knowledge and equipments?

The second question is, which seems very pertinent; Chandra Sekhar's model is based on a geocentric universe that has been " debunked" long since. At best his is a model resembling that of Tyco Brahe. Is it not that Tycho Brahe's data that were used by his one time assistant Kepler to turn the table on him to revert back to Copernicus's heliocentric model? So the question can be asked why should we bother to waste time on such a voluminous work based on "patently wrong" hypothesis?

Third question, which is more relevant to Indian context, is in what sense does it help us in scientific and technological advancement?

We shall try to address these three questions. In the sequel one recalls an outrageous remark by Macaulay, which claims that a single shelf of European Library contains more knowledge than the accumulated wisdom of all Sanskrit texts put together. The first question can be looked upon as a variant of the patently wrong arrogant remark of Macaulay. The author is by no means trying to arouse passion of patriotism or whip up a revivalist hysteria by this. Macaulay and his ilk suggest

that the nineteenth century India was intellectually no different from the primitive man steeped in ignorance guided by superstition. So the English conquerors would be fulfilling their missions of civilizing the Indians by revealing to them the marvels of modern science which tells them that all they have learnt were worthless and their salvation lay in rejecting it and worshipping the new God "the wisdom of the west".

Is it true that the land which taught the world reckoning of numbers, whose textile industry so unnerved the English business in the eighteenth century that they had to pass such stringent laws against import of Indian textile, that a person could be fined as much as £300/- for possessing a mere cotton handkerchief, whose ship building skills taught the Europeans to improve their own ship building skills- is so devoid of any scientific culture that it had to be rejected lock stock and barrel?

Astronomy has been with us ever since. We are not going in to the details of why and how Astronomy developed in India. As it is well known Astronomy has been one of the oldest sciences of the world. Every civilization produced its own astronomy and made contribution to it, which can be called significant. There is no denying of the fact that there were cross-cultural exchange and assimilation of ideas. Is it not true that Thales stunned the Greek audiences when he could accurately predict a solar eclipse, a method he learnt from the Babylonians? Did not Greek geometry develop because of their contact with the Egyptians? It is clear that the Greeks were quite ignorant of Astronomy and geometry before the 6^{th} century B.C. India had by that time developed quite sophisticated Astronomy as is clear from the *Vedānga Jyotisha.* Whether Indian astronomers borrowed from the Greek later is beside the point. Even if they did it proves nothing.

Astronomy percolated in to the very habits of Indians. Today in the west almost everybody talks of germs, infection etc. for example, but that does not mean everyone has a deep knowledge of pathology, micro-biology or anything like that. But the influence of Louis Pasteur has percolated to the lowest strata of the society. Similarly every Indian is no doubt, not an astronomer, but the knowledge of Astronomy has percolated to the very foundation of the society despite all attempts to keep it away from the lowly. The farmers still use astronomical conjunction for sowing, broadcasting, transplanting and harvesting. Interestingly enough they can still recognize a few constellation in the sky but the "modern" city dwellers cannot tell the Orion from the Cassiopeia.

It is curious to mention that the author's interest in astronomy grew out of his interaction with the tribals. In this context it is interesting to note that when the modern science comes in the school curricula it comes as a graft, as a transplant hardly ever trying to augment, improve, enrich or corroborate what is already known. India today is in a situation where there is a mass of people whose education has nothing to give to or take from this. It is needless to mention that this situation is hardly conducive to a scientific and technological advancement of a country.

We ought to look at Samanta Chandr Sekhar's work in this context. It was an attempt, which is more meaningful than the super imposition of knowledge, which we are trying, so to say, a legacy of what Macaulay thought.

Today particularly in India, there is hardly any intellectual pursuit. What we find today among the intellectuals is mere careerism. How many of us take it as a challenge to unravel the mystery of nature. How many of us want like Edison to pursue sciences so that it serves us better or makes us more comfortable? Most of us want to write a paper because it advances our career. It has been said that "wise men speak because they have something to say whereas fools speak because they have to say something". To which category do we "researchers" belong today? But what was the motive of this man called Chandra Sekhar? It was his passion for truth, which was his whole driving force. He did not have a career to improve. He neither coveted wealth nor hankered for honour. He had the courage of his convictions. He thought of something to be true and important to tell about it. He was prepared to tell that quite bluntly and emphatically without caring if it drew hostility of the orthodox or derision of the modern.

May be he was some times wrong. Once Professor Hardy remarked about Ramanujan that his mistakes were more wonderful than his success. It is interesting to quote "Nature" which published a review of *Siddhānta Darpana* in 1899 by Jogesh Chandra Ray: "What has he done after all?" ask the impatient critic. To him I would say – Is it not enough to find in this man a true lover of science; who regardless of other people's unfavourable opinions of his work, their taunts and derisions, has devoted all his life to the one pursuit of knowledge; who has shown the way to original research amidst difficulties serious enough to dishearten men in better circumstances; who has employed his time usefully instead of frittering away like usual run of men of his rank, on a work which guided the daily routine of millions of his countrymen". About his model of the solar system it is important to recall that even Einstein could not reconcile to the probabilistic interpretation of sub-atomic phenomena.

If phenomenon of Chandra Sekhar proves anything at all, it is that a handicap of seven centuries could hardly stop him from coming close to the most modern knowledge within a short span of eight years. Indomitable spirit of enquiry and a deep knowledge of the ancient wisdom, for whatever it was worth, achieved him what could be achieved in three centuries in west. If nothing he stands as an example to us what we can achieve in spite of our paucity of funds.

Coming to his geocentric model it is important to reiterate the following. After all the first of the inequalities of moon discovered by man is the equation of centre. It is the difference of the true anomaly and the mean anomaly, which is the observed periodicity of lunar motions. Greeks empirically observed this. But its derivation ultimately comes from the Kepler's laws; not only from the geocentric model of Ptolemy.

If we take the relative velocity $\mathbf{v}$ of moon with respect to the earth then we have from Kepler's law

$$V^2 = \dot{r}^2 + \frac{\mathbf{h}^2}{r^2} \tag{1}$$

But

$$\dot{r}^2 + \frac{\mathbf{h}^2}{r^2} = \mu\mathbf{2/r - 2/a)}$$

The true anomaly **v** is the angular distance measured from the perigee and if ω is

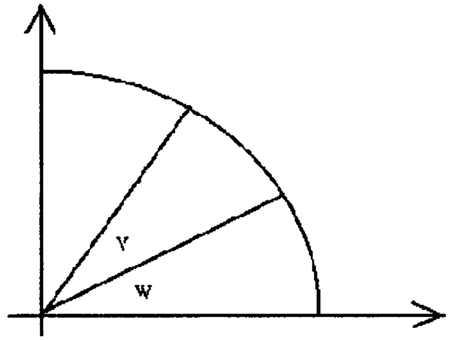


Fig. 1.

the angular distance of the perigee from the x-axis then we get

$$\begin{aligned} \theta &= \nu + \omega \\ \nu &= \theta - \omega \end{aligned} \tag{2}$$

The last part being derived from the Inverse square law

$$\begin{aligned} \ddot{r} &= -\frac{\mu}{r^3}\mathbf{r} \\ \dot{r}\cdot\ddot{r} &= -\frac{\dot{\mathbf{r}}\cdot\mathbf{r}}{r^3}\mu \end{aligned} \tag{3}$$

Because $\mathbf{r} \times \ddot{r} = 0$ we have $\mathbf{r} \times \dot{r} = h$, a constant vector. But $\frac{\mathbf{d}(\mathbf{r}\cdot\mathbf{r})}{\mathbf{dt}} = \frac{\mathbf{d}r^2}{\mathbf{dt}} = \mathbf{2\dot{r}}\cdot\mathbf{r}$. Substituting in (3) we have

$$\frac{\mathbf{d}(\dot{\mathbf{r}}^2)}{\mathbf{dt}} = \ddot{r}\cdot\dot{\mathbf{r}} = -2\mu\frac{\mathbf{r}\cdot\dot{\mathbf{r}}}{r^3} = -2\mu\frac{\dot{r}}{r^2} = \frac{\mathbf{d}}{\mathbf{dt}}(\frac{2\mu}{r})$$

From this we get

$$\dot{r}^2 = 2\frac{\mu}{r} + c \tag{4}$$

We observe (1) with (4) gives:

$$\dot{r}^2 = -\mu\left(r^2 - 2ar + \frac{h^2a}{\mu}\right)$$

It is clear that $r^2 - 2ar + \frac{h^2a}{\mu} \leq 0$ This is possible if $r_1 < r < r_2$ Where r_1 and r_2 are two roots of the equation:

$$r^2 - 2ar + \frac{h^2a}{\mu} = 0$$

It is clear that r_1 and r_2 correspond to perigee and apogee. We write

$$e = \frac{r_2 - r_1}{r_2 + r_1}$$
$$r_1 = a(1 - e)$$
$$r_2 = a(1 + e)$$

So that $r_1 r_2 = \frac{h^2 a}{\mu}$. This gives

$$h^2 = \mu a(1 - e^2)$$

$$r = a(1 - e\cos E)$$

[We recognize E as the eccentric anomaly] From these we get

$$r^2 - 2ar + \frac{h^2 a}{\mu} = a^2 e^2 \sin^2 E$$

Trying to integrate:

$$\dot{\mathbf{r}}^2 = \frac{-\mu}{ar^2}(r^2 - 2ar + \frac{h^2 a}{\mu})$$

we get

$$(1 - e\cos E)dE = \sqrt{\frac{\mu}{a^3}}dt.$$

$$\Rightarrow E - e\sin E = \sqrt{\frac{\mu}{a^3}}(t - \tau)$$

write $\frac{\mu}{a^3} = n$ and put $n(t - \tau) = M$, the mean anomaly. So we get

$$M = E - -e\sin E$$

Since $r^2 \dot{\nu} = h$ we have

$$\frac{d\nu}{dE} = \frac{\sqrt{1 - e^2}}{1 - e\cos E}$$

which implies

$$\frac{\tan\nu}{2} = \sqrt{\frac{1 + e}{1 - e}}\tan\frac{E}{2}$$

Since $r^2 \frac{dv}{dt} = h$ and $\frac{dM}{dt} = n$, we have

$$r^2 \frac{dv}{dt} = r^2 \frac{dv}{dM} \cdot \frac{dM}{dt} = nr^2 \cdot \frac{dv}{dM} = h$$

$$r^2 \frac{dv}{dM} = \frac{h}{n}$$

This gives

$$\frac{\sqrt{1 - e^2}}{(1 + e\cos\nu)^2} \cdot \frac{dv}{dM} = 1$$

$$M = \int_0^\nu \frac{(1-e^2)^{3/2}}{(1+e\cos t)^2}dt$$

Expanding the denominator in powers of e and integrating we get

$$M = \nu - 2e\sin\nu + \frac{3}{4}e^2\sin 2\nu + o(e^2)$$

Trying to express v in terms of M we get:

$$\begin{aligned}\nu &= M + 2e\sin(M + 2e\sin\nu) - \frac{3}{4}e^2\sin 2\nu + o(e^2)\\ &= M + 2e\sin M + \frac{3}{4}e^2\sin 2M + o(e^2)\\ \nu - M &= 2e\sin M + \frac{5}{4}e^2\sin 2M + o(e^2)\end{aligned}$$

For the Moon's orbit we have $e = 0.05490$. The above gives us the equation of centre

Perturbation of Moon's orbit can be obtained from the Brown's[2] formula

$$\lambda = L\sum a_{ijkl}\sin(iM' + jM + kF + lD) \tag{5}$$

$$\beta = \sum b_{ijkl}\sin(IM + jM + kF + ID) \tag{6}$$

$$\sin P = \sin P_0 + \sum ci_{jkl}\cos(iM + jM + kF + iD)$$

Where the coefficients a_{ijk} *and* b_{ijk} are coefficients depending on the various parameters of the orbit[1].

An approximate solution to the above equation as follows:

$$\lambda = L{+}6^0.29\sin M{-}1^0.27 \sim (M{-}2D){+}0^0.66\sin 2D{+}0.21\sin M{-}0^0.19\sin M{-}0^0.11\sin 2F \tag{7}$$

where$F = L - \Omega$

The term involving Sin M' stands for the equation of the center, coefficient of Sin (M' - 2D) is maximum value of evection, the next coefficient of Sin 2D is the variation and the next one is annual equation. These three were discovered by labourious observation by Chandra Sekhar.

The calculations above are based purely on the geocentric co-ordinates. This ought to dispel our doubt about effectiveness of the model due to Chandra Sekhar for calculation of ephemeris at least for the moon. No doubt an exact solution of an n-body problem is quite an impossible task. No one attempts to get the position of all the planets of the solar system, the sun, and the moon by solving the system of 10 equations it involved. In fact that is the reason for the concept of the osculating ellipse with which every astronomer is familiar.

All co-ordinates are with reference to earth. The co-efficients a_{ijkl} can be numerically computed. They depend on many small quantities like the eccentricities of two

mean orbits of moon and the sun, inclination i, ratios of the semi major axes of two orbits etc.

We have already seen that equation of the centre is derived from a solution of the equation

$$M = \int_0^{\nu} \frac{\sqrt{1-e^2}}{(1+\cos\nu)^2} d\nu$$

as a power series in **e** , which converges and evaluated upto two terms agree with the observed value. Similar thing can be told about the other co-efficients in (7).

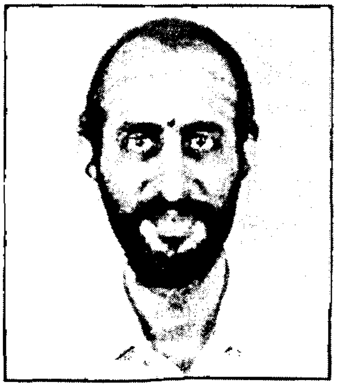
So if Samanta Chandra Sekhar took a geocentric model, it is beside the point. His geocentric model like Tyco Brahe's were from the positional point of view relative co-ordinate system, with respect to the earth. Neither he nor Tyco Brahe tried to derive the equation of the centre, evection, variation, or annual equation from the model. When finally the equation of the centre was derived it was after the Kepler's laws had been finally established. It took almost three centuries since the time of Tyco Brahe to derive the three different irregularities of the moon from Brown's theory and Hill's equations (if Clemence & Sadler [1]).

Coming to the third question as to how the work of Samanta Chandra Sekhar is relevant for the scientific and technological development of India, it is important to note, as has been pointed out earlier that the one and half century of western education perpetrated in India has hardly meant anything to the large mass of Indian people who have been marginalized over the years. We yet don't know how to remedy the situation. The phenomenon of Chadra Sekhar ought to teach us where to begin .His simple instruments whose construction was so inexpensive, could measure not only the angular displacements of the heavenly bodies but could also be used to measure the heights and distances of terrestrial bodies like mountains. Why is it that when children are taught to calculate heights and distances in trigonometry, they cannot be given a few of these inexpensive instruments to satisfy themselves that after all what they are learning to calculate is meaningful. The next point is *panjikā* or *pānchang* is an indispensable part of our social life. This tells us various conjunctions like full moon, eclipses etc. Unfortunately this instead of developing a scientific attitude in us, strengthens our superstition in giving us a false impression of predicting the future of individuals, or finding auspicious moments for travel, inauguration etc. In India today astronomy and astrology are confused for one another. It is important to note that the Samanta had no confusion in his mind about the distinction of these two. (cf. XV 61, *Siddhānta Darpana*[4]) He has categorically said that he wanted to expound mathematical astronomy not astrology. His was an attempt to present an astronomical text, which even children can understand to use his own words, without sacrifice of accuracy and rigor. So in a way he was one of the earliest attempts at de-mystification of astronomy. It is noteworthy that Tyco Brahe in an attempt to prove his model made a detailed and meticulous observation of motion of the planets. The enormous data collected by him and his assistant Kepler eventually led to the formulation of the Kepler's laws. These laws were used by Isaac Newton to get his inverse square

law of gravitation. In a way positional astronomy is a precursor of the theories of Physics by Newton. We recall that an observation of the planet Mars by Kepler led him to conclude about constancy of the areal velocity swept by the radius vector joining the focus to the planet, which of course was later recognized as conservation of angular momentum. Chandra Sekhar's observational data are not available to us. But Chandra Sekhar suggests in his works that the orbits of planets are elliptical. If he had more time and access to better equipments he perhaps could have discovered Kepler's laws. Chandra Sekhar has shown the way in which scientific temper can be inculcated in India. In fact, his was an attempt to dispel the awe with which people regarded the science of astronomy and concomitant superstitions. He gives us how we shall ensure that most modern knowledge of science attained by a few can really percolate and spread among the masses. The idea is to grow from what we already have and are almost about to forget. Astronomy somehow still determines the daily routine of our countrymen as pointed out by Acharya Jogesh Chandra Ray. People still go by the almanac rather by the western calendar. It is from this we ought to start to spur awareness in science. It is urgent that a modern scientific edition of *Siddhānta Darpana* is available in the mother tongue as well as in English.

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Planetary Models in Indian Astronomy and Contributions of Samanta Chandra Sekhar*

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1 Introduction

The belief that the long history of Indian astronomy beginning from Aryabhata of Kusumapura (476 AD) came almost to an end with Bhaskaracarya (1114 AD) was found to be mistaken and it is now well known that this science flourished at-least in Kerala during 13th - 18th century. A few prominent Kerala astronomers of this period are Madhava, Parameswara, Nilakantha Somayaji, Jyesthadeva etc. Perhaps Samanta Chandra Sekhar was the last to come in the Indian tradition of astronomers who has made remarkable contributions to improve the parameters used for computation of longitudes, latitudes, eclipses etc. to get more accurate results.

2 A brief account of some important contributions of Kerala astronomers

Madhava of 14th century is known for the infinite series expansions of irrational numbers such as Π and trigonometric functions such as $\sin x$, $\cos x$, tan^{-1} x etc.

Parameswara of 15th century notices that the predictions based on the *Parahita*-system, introduced by Haridatta around 8th century AD went off the mark. Having realized that the errors due to the approximations used in the *Parahita*-system would have piled up over a few centuries, he introduced a new system called *Drk*-system. It is quite remarkable that Parameswara one of the astute astronomers ventured to introduce *Drk*-system only after making systematic observations for about 55 years. It is for this reason, he is held in high esteem by later astronomers. He was also a prolific writer and a number of works (around 30) are credited to him.

Nilakantha Somayaji of 15th-16th century is recognized by later astronomers for his seminal works such as *Aryabhateya-bhashya, Tantra-sanghraha* etc., In the II chapter of *Tantra-sangraha* two things are worth noting. While giving the formula for getting the instantaneous rate of motion of a planet he gives the following verse. The above verse when written in mathematical notation amounts to

$$\frac{\frac{r}{R} M \frac{dM}{dt}}{[1 - (\frac{r}{R}\sin M)^2]^{\frac{1}{2}}}$$

* Work done in collaboration with M. D. Srinivasa and M. S. Sriram of the same department during 1991-94.

चन्द्रबाहुफलवर्गशोधित-त्रिज्यकाकृतिपदेन संहरेत् ।
तस्यकोटिफललिप्तीकाहतां केन्द्रभुक्तिमिह यच्च लभ्यते ॥

(Tantra-sangraha 2.53)

where $r \longrightarrow$ radius of *manda* epicycle
$R = 360^o$
$M \longrightarrow$ mean anomaly

which is same as the expression for the derivative of $\sin^{-1} x$, where $x = \frac{r}{R} \sin M$.

Latter in the chapter, while discussing the '*samskaras*' (i.e. corrections to be applied to get the apparent or geocentric longitude from the mean longitude) for the planets, he formulates the correct application of 'equation of centre' for the inner planets (Mercury and Venus). To our knowledge he is the first in the history of astronomy to enunciate proper application of 'equation of centre' and also to provide the rationale behind it. A detailed account of how Nilakantha arrived at this formulation is found in his *Aryabhatiya-bhashya.*

The following verses describe the model of planetary motion as given by Nilakantha Somayaji in his *Siddhānta-darpana.* The verses are followed by their true (not free) translations. Figures 1 and 2 illustrate the geometric models of the inner and outer planets respectively.

ग्रहभ्रमणवृत्तानि गच्छन्त्युच्चगतीन्यपि ।
मन्दवृत्ते तदर्केन्द्वोः घनभूमध्यनाभिकम् ॥
मध्यार्कगति चान्येषां तन्मध्यं शीघ्रवृत्तगम् ।
तेषां शैघ्र्यं भचक्रान्तविक्षिप्तं गोलमध्यगम् ॥
शैघ्र्यत्वेन तदंशैः स्वं प्रमायोक्तं ज्ञशुक्रयोः ।
मन्दवृत्तस्य चैवात्र क्षयवृद्धी स्वकर्णवत् ॥

(Nilakanta's Siddhanta Darpana 17-19)

The (eccentric) orbits in which the planets move [*grahabhramana-vrtta*] themselves move at the same rate as the apsides [*ucca-gati*] on *manda-vrtta* [viz., *manda* epicycle

drawn with its centre coinciding with the manda concentric]. In the case of Sun and the Moon, the centre of the Earth is the centre of *manda-vrtta.*

For the others [namely the five planets Mercury, Venus, Mars, Jupiter and Saturn] the centre of *manda-vrtta* moves at the same rate as mean Sun [*madhyarka-gati*] on the *sighra-vrtta* [viz., *sighra* epicycle drawn with its centre coinciding with he *sighra* concentric]. The *sighra-vrtta* for these planets is not inclined with respect to the ecliptic and has the centre of the celestial sphere [Earth] as its centre.

In the case of Mercury and Venus, the dimension of the *sighra-vrtta* is taken to be that of the concentric and the dimensions [of the epicycles] ,mentioned are of their own orbits. Further, here the *manda-vrtta* [and hence the epicycle of all the planets] undergoes increase and decrease in the size in the same way as the *karna* [the hypotenuse or the distance of the planet from the centre of the *manda* concentric].

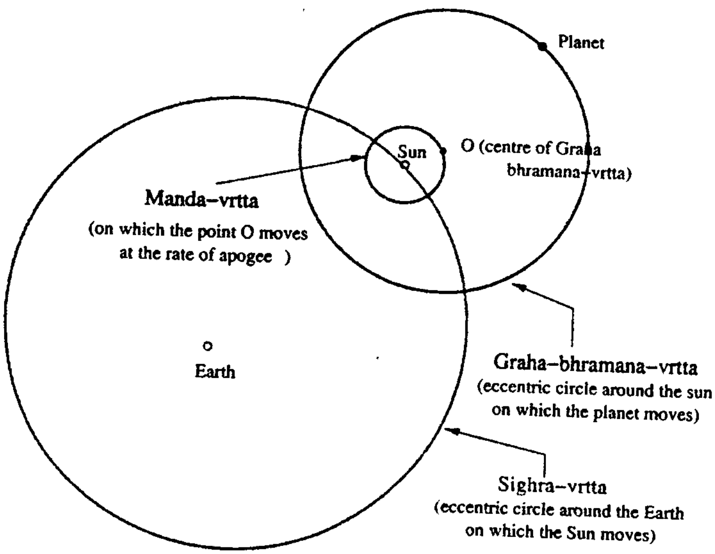


Fig. 1. Geometric model for inner planet as given by Nilakantha

Jyesthadeva of the later part of 17th century is well known for his exposition in Yuktibhasha. As the name of the work itself suggests, it gives '*yukti*', rationale for the procedures used in the calculation of longitudes. One of the unique features of *Yuktibhasha* is that one finds mathematical proofs of some of the formulae used by earlier contemporary astronomers for numerical computations. It also gives a detailed account of the geometrical models of planetary motion implicit in the calculational procedures. Wherever possible *Jyesthadeva* also establishes the correspondence between different approaches used for the computation of the same quantity.

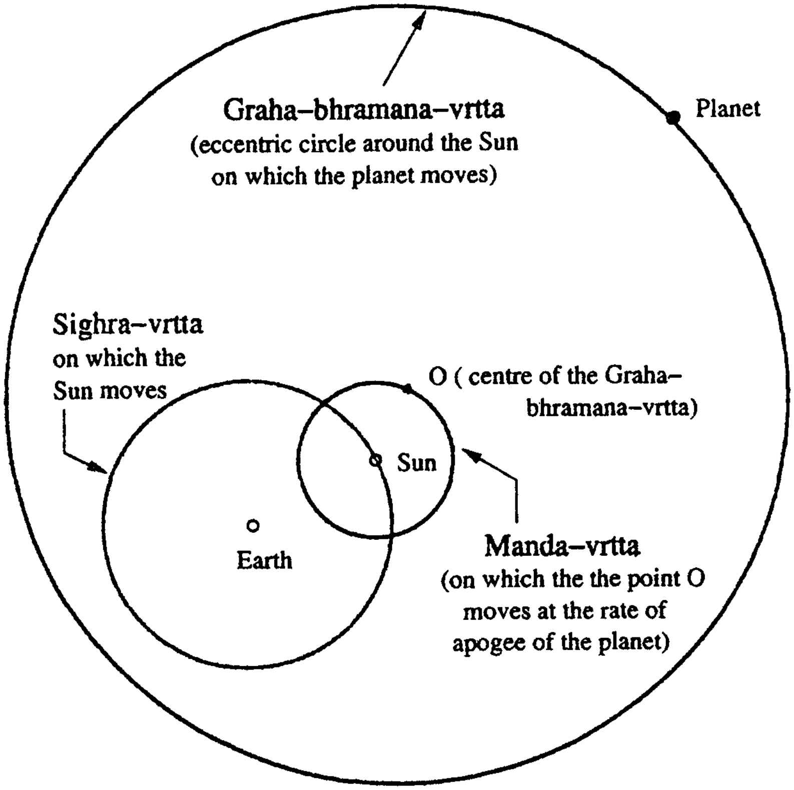


Fig. 2. Geometric model for outer planet as given by Nilakantha

3 Importance of observation as pointed out by Indian astronomers

This section (though not directly related to the title of the paper) is included to inform the readers about the motivation with which the science of astronomy was pursued in India. It seems to us that the main aim of Indian astronomers was to see that the predictions of time of occurance of various astronomical events such as sunrise, sunset, eclipses, etc., which were directly related to the religious and social observances of the society agree, with the observational values.

All the astronomers right from Aryabhata of 5th century to Samanta Chandra Sekhar of 19th century invariably give importance to the science of observation. They strongly suggest that the parameters used for the calculation be modified if discrepancies were noticed between prediction and observation. It is noteworthy that the Indian astronomers were not wedded to any particular model of the planetary motion. It is also recommended that a '*Jyotishacarya*' should be well-versed both in *Ganita* and *Jataka-skandha* (i.e. astronomy and astrology). In fact, a mere astrologer is strongly criticized. In this context we would like to make a few quotations from astronomers of different periods including Orissa's illustrious son Samanta Chandra Sekhar.

Aryabhata: Towards the end of the text *Aryabhatiya*, Aryabhata mentioning about the origin of his work observes:

सदसद्ज्ञानसमुद्रात् समुद्धृतं देवताप्रसादेन ।
सज्ज्ञानोत्तमरत्नं मया निमग्नं स्वमतिनावा ॥

(Aryabhatiya Golapada 49)

'From the ocean of knowledge which consists of truth and false [*sada-sat*], I have picked up the gem of truth (i.e., correct) by delving (into the ocean) through the boat of intellect and '*Devata-prasada*' (gift of god).'

A detailed analysis of the work '*Devata-prasada*' (gift of god) is made by Nilkantha Somayaji in one of his interesting works *Jyotirmeemamsa.*

Varahamihira: Varahamihira in his *Brhat-samhita*, while listing the qualities of a Jyotishacarya in great detail states:

सौरादीनां मानानां असदृश-सदृशयोग्यायोग्यत्व प्रतिपादनपटुः ॥
सिद्धान्तभेदेपि अयननिवृत्तौ प्रत्यक्षसममण्डललेखासंप्रयोगाभ्युदि-
तांशकानां छाया जलयन्त्र-दृग्गणितसाम्येन प्रतिपादनकुशलः ॥

(Brhat-samhita 2.7-8)

'A *Jyotishacarya* should be an expert in explaining the similarities and dissimilarities of different systems. He should also be able to say the correctness or otherwise of a particular text.'

'Even if *siddhāntas* differ in predicting the ending moment of a '*Ayana*' (transit of an equionox), a good astronomer should be able to verify and reconcile them by conducting experiments with gnomon(*sanku*) water-wheel instrument, etc.

Bhaskaracarya: At the very beginning of his classic text *Siddhanta Siromani*, Bhaskaracarya makes sarcastic remarks about a *Jyotishacarya*, who considers himself knowledgeable just by mastering the astrological texts and knowing to just make a few elementary calculations, without studying *siddāntic* text. He states:

जानन् जातकसंहिता ....

यः सिद्धान्तमनन्तयुक्तिविततं नो वेत्ति भित्तौ यथा

राजा चित्रमयोऽथवा सुघटितः काष्ठस्य कण्ठीरवः ॥

(*Sid.Sir.,Madhyamadhikara 1.7)*

'By knowing astrology .... one who does not know a siddhanta, which deals with all the facets of the science of astronomy, giving rationale behind the rules, is comparable to painting of a king on a wall or a well carved and painted lion made of a log. '

Parameswara: Parameswara one of the most reputed Kerala astronomers, introducing the *Drk*-system of astronomy observed:

दृश्यन्ते विहगा दृष्टया भिन्नाः परहितोदिताः ॥

प्रत्यक्षदृष्टाः स्पष्टाः स्युः ग्रहाः शास्त्रेष्वितीरितम् ॥

सत्कर्मोदितकालस्य ग्रहा हि ज्ञानसाधनम् ।

अस्पष्टविहगैः सिद्धः युक्तः कालो न कर्मणि ॥

ये तु शास्त्रविदस्तद्वत् गोलयुक्तिविदश्च तैः ।

स्फुटखेचरविज्ञाने यत्नः कार्यो द्विजैरतः ॥

(Drgganita 1.1.2-6)

'The predictions of the positions of the planets from the *Parahita* system differs from the observed values. It is mentioned in *sastra* that the observed positions are the correct ones.'

'The planets (planetary positions) are the means to determine the times (of observation) of auspicious rites. The times determined from the wrong planetary positions re not the correct ones for the observation of rites. '

'Therefore (to avoid observing rites at the improper moments) those who are experts in this science (viz., mathematics and astronomy) [*sastra-vidah*], and those who are good at spherics [*gola-vidah*] should make efforts to predict the true position of the planets.'

The kind of reputation which Parameswara enjoyed is explicit from the works of later astronomers. For instance, Nilakanta in his *Aryabhatiya-bhashya* states

परमेश्वरार्येणपुनः ग्रहणग्रहयोगादिकं यन्त्रैः पञ्चपञ्चाशद्वर्षकालं
सम्यक् परीक्ष्य तस्य गोलवित्तमत्वञ्च गोलदीपिकादिभिः
तत्कृतैः प्रबन्धैः ज्ञायते ॥

(*Aryabhatiya-bhashya Golapada 49*)

The eclipses, conjunctions of planets etc., were examined with instruments for 55 years by revered Parameswara. His expertise in spherics [spherical astronomy] is reflected by his works like *Gola-dipika* etc.

Parameswara having made observations over a long period of about 55 years decided to author a few texts at the request of his disciples. While composing the text based on his own observations, he modestly makes the following statement which reflects the importance that he associates for the pursuit of science.

कालेनानेन च सिद्धः कदाचिदपि भिद्यते स्वल्पम् ।
कालान्तरे तु संस्कारः चिन्त्यतां गणकोत्तमैः ॥

'The parameters inspite of being determined after observing for along period, the predictions based on them at times, differ slightly (from the observed values). Let the foremost among the mathematicians, think of other *samskaras* [corrections to be applied] at a later date.'

Nilakantha: Nilakantha reconciling the differences in the number of revolutions of planets given in different texts observes:

'The number of revolutions as given by the Acharyas are different because of the fact that the number of revolutions (made by the celestial objects in a specific period, say *Mahayuga* 43,20,000 years) are not (exactly) integers [*savaya-vatvaat*]. Because the decimal part is long, and with the evolution of time they get multiplied, [the discrepancies build up]. These discrepancies [*sthoulyam*] which accumulate have to be discarded [rectified] by evidences [*pramana*] such as *pratyaksha* etc. [i.e. results based on the perception of senses etc.].'

He also goes to the extent of advising his students to note down all the details of their observation carefully. He states:

'By the results of your own observations and that of your ancestors [*pratyaksha* and *eitihya*], the rate of motion of the planets and apsides have to be determined.

यत्पुनर्भगणादीनां क्वचित् केषाञ्चिदाचार्यैः नानाप्रतिपादनं
तत्परिमाणानां सावयवत्वात्, अवयवानाञ्च आनन्त्यात्,
कालदैर्घ्यात् तदावृत्तौ तदवयवानां गुणितत्वात्, यद्वर्धमानं
स्थौल्यं, तदपि तन्मूलप्रमाणैः प्रत्यक्षादिभिरेव निराकार्यम् ॥

(*Aryabhatiya-bhashya Golapada 48*)

प्रत्यक्षैतिह्ययोगाभ्यां ज्ञेयाः खेटोच्चयोर्गतिः ।
लेख्यं तत् पुस्तके शिष्यैः पद्यं वा गद्यमेव वा ॥
संस्कृतैः प्राकृतैर्वापि स्वीयया देशभाषया ।
अप्रमत्तेन विज्ञेयाः सर्वे लेख्याः प्रयत्नतः ॥

(*Aryabhatiya-bhashya Golapada 48*)

These [observations] have to be written down in a notebook by the disciples either in the form of prose or poetry.

[Observations could be written down] either in Sanskrit or in Prakrit or in their own regional languages. Things have to be observed carefully with great effort and al [the observations] have to be noted down meticulously.'

Samanta Chandra Sekhar: At the very beginning of the work, having stated that the purpose of his text, Samanta Chandra Sekhar devotes a few verses to explain the speciality of this science [*Jyotisha-sastra*] as compared with the other sciences. While pointing out the importance of observation in this discipline he observes:

नास्ते कालावयवकलना यत्र हक्शास्त्रसिद्धा
श्रौतस्मार्तव्यवहृतिरपि छिद्यते तत्र धर्माः ।
तस्मादेषाकृतिरनृतवागस्तु वा प्रस्तुतार्था
ग्राह्या दक्षैः ग्रहणभगणाद्यत्र संलक्ष्य साक्षात् ॥

(*Siddhānta-darpan 1.6*)

'If the divisions of time (i.e. predictions of sunrise, sunset times and that of the ending moments of *tithis* etc.,) are not in concordance with observations, the sacrificial and social rituals [*srouta and smarta dharmas*] which have time as one of the components i.e., *angas*] get shattered. Therefore [to avoid this], I compose this work. The predictions based on this text could go wrong or may fulfill the requirement. Let the competent ones having tested the number of revolutions and verifying the eclipse prediction, decide the acceptibility of this work.'

He further states:

यदैव दृग्गोचरतां यदेति तदा तदेवाद्रियते हि शास्त्रम् ।

(*Siddhanta-darpan 1.9*)

'That text, the predictions of which agree with the observations is alone recognized (as the correct one).'

4 Date of composition, purpose and the style of *Siddhānta Darpana*

4.1 Date

While giving the divisions of time in detail, Samtnta Chandra Sekhar makes a passing statement as follows:

अत्रान्तरे यातवती युगानां सप्ताधिकविंशतिरन्यतश्च ।
युगाहताः सत्यमुखत्रिपादाः कलेः खसप्ताङ्कमहार्णवाब्दाः ॥
याताःस्युरेतद्भगणोक्तिकाले----

(*Siddhanta-darpana 1.42-43*)

'In the meantime three-fourths and twenty seven '*catur-yugas*' have elapsed. Even in the *Kaliyuga* 4970 years have elapsed, when these number of revolutions are being stated ...'

Since the beginning of *Kaliyuga* is taken to be February 17-18th midnight 3102 B.C., it may be inferred from the above verse that the time of composition of the work could be around 1869 AD.

4.2 Purpose

The purpose of *Siddhānta Darpana* as stated by Samanta Chandra Sekhar is two-fold:

1. To Achieve concordance between prediction and observation.
2. To compose a text which is well within the reach of even ordinary mathematicians.

At the very outset of his work Samanta with lot of confidence on his work states:

तत्तद्ग्रन्थेषु यस्मिन्नभवति सुमहत्तारतम्यं ग्रहादेः
दृक्संवादात् स तथ्यः बहुतरमतः कथ्यतेऽ सावतथ्यः ।
पूर्वाचार्यैः, तदस्मद्ग्रथनमपि चिरस्थायि दृक्सिद्धभावात्
अव्यर्थं ---

(*Siddhanta-darpana 1.8*)

'The ancient acharyas consider only those texts as correct ones [*tathya*] the predicted values of which, do not differ much from the observed ones. If the difference is too much they are not considered to be correct. This work (I believe) would stay for a long time since the predictions have been confirmed with observations. (Therefore I feel that this effort of composing a text) may not go in vain ...."

In yet another place, he clearly states the purpose of his work as follows:

श्रीभास्करप्रभृति खेचरचक्रवालं नत्वा गुरुं स्वपितरौ तदनुग्रहाढ्यः ।
मूढोप्यगाढगणकप्रतिपत्तयेऽहं सिद्धान्तदर्पण इति प्रथयामि शास्त्रम् ॥

(*Siddhanta-darpana 1.4*)

'Having paid homage to Bhaskaracarya etc., who are stalwarts of astronomy [*khera-cakravalam*] and my parents to receive their blessings, though I am not an expert, I compose this text for the understanding of average mathematicians [*aghadha-ganaka*].'

The concluding verse of every chapter reads as follows:

इत्युत्कलोज्वलनृपालकुलप्रसूत-श्रीचन्द्रशेकरकृतौ गणितेऽक्षिसिद्धे।
सिद्धान्तदर्पण उपाहितबालबोधे ------

'Here again the term '*bala-bodha*' means for the understanding of those who are not well versed in this discipline.

We would also like to mention here that the clarity and elegance with which this text has been written can be better appreciated if only one tries to digest some of the earlier works on Indian Astronomy like *Aryabhatiya, Siddhanta Siromani, Khandakhadyaka, Laghumanasa*, etc. The speciality of *Siddhānta Darpana* of Samanta lies in the fact that even without a formal background in the discipline one would be able to follow the text without much difficulty.

4.3 Style

Regarding the style of composition of *Siddhānta Darpana* one could say that it is very simple, flowing and straight forward. Most of the chapters begin with verses giving the contents of the chapter. For example consider the following few lines:

अथाभिवाञ्छिते वर्षे मासे पक्षे तिथावपि।
तापनैन्दवमानोत्थसावनाहर्गणक्रमात्॥
मध्यग्रहाद्यमानेतुं स्थापयेत् कल्पवक्त्रतः। ....

(*Siddhānta-darpan 3.1-2*)

अथोच्यते स्वदेशादिसंस्कारार्थं समासतः।
भूमानमुत्तरे भागे विस्तराद्वक्ष्यते पुनः॥

(*Siddhanta-darpan 4.1*)

अथोच्यते महीनिष्ठदृष्टितुल्या स्फुटीकृतिः।
ग्रहाणां फलदातृत्वं न घटेत यया विना॥

(*Siddhanta-darpan 5.1*)

The above verses are in '*Anushtup*' metre and more than 95% of the text has been composed in this metre which is the simplest of all the metres in Sanskrit poetry. With the choice of this metre, the author would not be constrained to use difficult or unfamiliar words/compounds. As a result the composition could be followed without much difficulty even by those who do not have sound knowledge of Sanskrit.

5 Picture of Planetary motion of Samanta Chandra Sekhar

In the chapter on '*graha-sphutikarana*' (correcting the planets i.e., planetary positions) Samanta Chandra Sekhar after stating the need for '*sphutikarana*' gives a clear picture of the planetary motion.

प्रवहाख्यो मरुद्भूमिं परिक्रमति सर्वदा ।
पश्चिमाभिमुखस्तेनाकृष्टो ज्योतिर्गणोऽन्वहम् ॥
यान्ति यत् पश्चिमामाशां उदिता साह्निकी गतिः ।
तां भित्वा यद्ग्रहगणः स्वस्वभुक्त्यनुसारतः ॥
स्तोकेन याति पूर्वाशां सोक्ता स्वाभाविकी गतिः ।
शीघ्रमन्दवशाद्भिन्नाः दृश्यन्ते स्फुटखेचराः ॥

(*Siddhanta-darpan 5.2-4*)

'A wind by name '*pravaha*' always goes around the Earth. The galaxy of celestial objects is always [*anvaham*] drawn by it towards west. The motion of these objects towards west, till they rise again is called diurnal motion [*anhiki-gati*]. The slow eastward motion of the celestial objects against the westward motion at their own rates is their actual motion [*svabhaviki-gati*]. The true positions (of these objects) are seen to be different (from the mean) because of the effect of '*sighra*' and '*manda*' (viz., the orbits of the planets are not geocentric but are eccentric around the Sun).

तत्र मध्यममार्तण्डः परितो मण्डलं भुवः ।
भ्रमन् ताराखेचराणां कक्ष्यामध्यस्थ उच्यते ॥
तं भ्रमन्तो महीजाद्याः तत्सङ्गेन भुवं पुनः ।
परिक्रमन्ति यत्तस्मात् स प्रोक्तः सर्वकर्षकः ॥
तथापि कुजजीवार्किभुक्तिभ्यो महती यतः ।
तद्गतिः सततं तेषां शीघ्रतुङ्गो निगद्यते ॥
बुधशुक्रस्वभुक्तिभ्यां अल्पत्वात् भास्वतो गतेः ।
तयोर्मध्यग्रहो भानुः स्वयं तौ शीघ्रसंज्ञकौ ॥

(*Siddhanta-darpan 5.6-9*)

'The mean Sun revolving around the Earth is considered to be at the center of the '*Kaksya-vrtta*' [*manda* concentric] of the planets.'

'The planets Mars etc., going around the Sun also go around the Earth because of his contact. Since they move along with him, he is stated to be the attractor of all.'

'Since its daily motion is much smaller than that of mercury and Venus, Sun is considered as their mean planet and they themselves are referred as '*sighra*' (for calculational purposes).'

The author then gives a graphic description of the situations of the orbits of the planets around the Sun in the following verse:

बुधशुक्रावनीपुत्रबृहस्पतिशनैश्चराः ।
सूर्यात् क्रमेण दूरस्थाः स्वस्वकक्ष्यासु यान्ति यत् ॥

(*Siddhānta-darpan 5.10*)

'The Mercury, Venus, Mars, Jupiter and Saturn in their manda concentric circle [*kakshya-vrtta* i.e. circle centered around the Sun in the case planets] are at greater distances from the sun respectively.'

The overall picture of the planetary motion as given by Samanta Chandra Sekhar is given in Figure 3. The remark made by Samanta regarding the motion of Moon

is interesting to note. While most (all ?) of the Indian astronomers before Samanta assume the linear velocity of all the planets to be the same, he states:

चन्द्रस्यत्वर्कवद्भ्रान्ति भूमेर्निकटवर्तिनः ।
योजनात्मगतिर्न्यूना महतीलिप्तिकात्मिका ॥

(*Siddhanta-darpan 5.12*)

'The motion of the Moon, which lies close to the Earth, resembles that of the Sun. Though its motion in *yojanas* (linear distance covered) is less than that of the Sun, the motion in angles (angular distance covered) is much greater.'

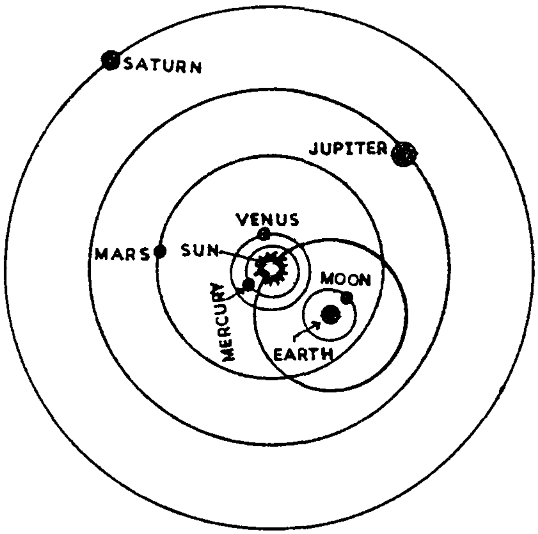


Fig. 3. Picture of planetary motion given by Samanta Chandra Sekhar

6 Results of the calculation of longitudes

To see the accuracy of the predictions made by Indian astronomical texts with regards to the planetary positions, the calculation of the *Nirayana* longitudes according to eight different texts composed at different epochs, beginning from the 5th century to 19th century, were taken up. The calculations are made for 30 days spanning over the

sidereal period of the planet. The results obtained were compared with the modern values (generated by a software written in late 80's). In the tables given below, for two planets namely Moon and Jupiter, we have indicated the date of calculation [column 1], the modern value of the longitude [column 2] and errors [*Nirayana* longitude as given by the text - modern value] in columns 3-10.

The symbols used in the table for the name of the text, as explained below. The authors along with the time of composition is also indicated.

AB	*Aryabhatiya* of Aryabhata	499 AD
KK	*Khanda-khadyaka* of Brahmagupta	665 AD
LM	*Laghu-manasa* of Manjulacarya	932 AD
SS	*Surya-siddhanta* of unknown author	10th century
SI	*Siddhanta-siromani* of Bhaskaracarya	1150 AD
GL	*Graha-laghava* of Ganesa Daivajna	1520 AD
TS	*Tantra-sangraha* of Nilakanta Somayaji	1500 AD
SD	*Siddhanta Darpana* of Samanta Chandra Sekhar	1869 AD

Towards the end of each of the tables, the Mean, Rms, Maximum and the Minimum errors are listed. It may be noticed that the errors obtained, based on the calculations of *Siddhānta Darpana*, are remarkably small compared to the errors given by the other texts.

In the case of Moon, it is seen that the Rms error given by *Siddhānta Darpana* is just 20 minutes, whereas for all the other texts it is greater than a 1.3 degrees. This is not because of improved (more accurate) value of daily motion given by *Siddhānta Darpana* but because of the four correction terms given by the author instead of one given in the other texts.

In the case of Jupiter, also it is seen that the Rms error given by *Siddhānta Darpana* is very small. It is less that 12 minutes for this text, whereas, all the other texts but for *Tantra Sangraha* give a value greater than 2 degrees. Here again (and in the case of planets in general) the accuracy obtained is not because of the very accurate value of daily motion given by *Siddhānta Darpana* but because of the choice of *Dhruvas* [i.e. the initial values of the longitudes of the planets chosen at the epoch]. Of course it is true that this text gives better values of the daily motion in the case of planets, but this does not matter as much as the *dhruvas* matter.

Planet: Moon
(Longitudes and Errors in Degrees)

Table 1. *Nirayana* longitudes of the Moon for 30 days spanning over its own sidereal period of about 28 days. Column 2, gives the actual longitude (computed using modern methods) whereas the other eight columns give the error/deviation of the longitudes, as obtained using eight different texts, from the actual value. The last four rows give the mean, rms, maximum and the minimum value of the error obtained using that particular text.

Name of	the text	AB	KK	LM	SS	SI	GL	TS	SD
1/9/1994	75.004	3.323	2.095	-1.080	1.206	3.498	0.929	0.665	0.276
2/9/1994	87.722	3.101	1.862	-0.924	1.068	3.491	0.834	0.608	0.049
3/9/1994	100.828	2.717	1.461	-0.862	0.778	3.355	0.591	0.408	-0.217
4/9/1994	114.334	2.181	0.902	-0.895	0.342	3.089	0.208	0.065	-0.468
5/9/1994	128.217	1.528	0.222	-1.001	-0.211	2.713	-0.289	-0.395	-0.654
6/9/1994	142.417	0.816	-0.521	-1.144	-0.831	2.268	-0.852	-0.926	-0.731
7/9/1994	156.843	0.118	-1.251	-1.274	-1.444	1.816	-1.419	-1.462	-0.682
8/9/1994	171.387	-0.487	-1.888	-1.341	-1.976	1.423	-1.920	-1.934	-0.518
9/9/1994	185.945	-0.933	-2.365	-1.317	-2.364	1.141	-2.292	-2.284	-0.286
10/9/1994	200.427	-1.180	-2.639	-1.194	-2.568	1.006	-2.492	-2.475	-0.046
11/9/1994	214.786	-1.218	-2.699	-0.995	-2.578	1.020	-2.500	-2.499	0.143
12/9/1994	228.930	-1.066	-2.563	-0.761	-2.423	1.163	-2.367	-2.377	0.241
13/9/1994	242.895	-0.764	-2.272	-0.547	-2.147	1.393	-2.216	-2.148	0.238
14/9/1994	256.658	-0.365	-1.875	-0.402	-1.789	1.663	-1.816	-1.860	0.146
15/9/1994	270.220	0.080	-1.425	-0.362	-1.424	1.927	-1.483	-1.558	0.007
16/9/1994	283.580	0.529	-0.964	-0.442	-1.062	2.152	-1.164	-1.279	-0.148
17/9/1994	296.753	0.952	-0.523	-0.638	-0.736	2.320	-0.886	-1.044	-0.282
18/9/1994	309.679	1.333	-0.118	-0.923	-0.455	2.429	-0.660	-0.857	-0.375
19/9/1994	332.408	1.668	0.246	-1.263	-0.217	2.488	-0.479	-0.713	-0.417
20/9/1994	334.918	1.968	0.577	-1.611	-0.009	2.524	-0.325	-0.591	-0.406
21/9/1994	347.217	2.243	0.885	-1.925	0.185	2.561	-0.175	-0.471	-0.354
22/9/1994	359.324	2.507	1.180	-2.168	0.379	2.623	-0.009	-0.332	-0.276
23/9/1994	11.271	2.770	1.473	-2.314	0.586	2.731	0.186	-0.158	-0.190
24/9/1994	23.105	3.033	1.762	-2.349	0.810	2.896	0.407	0.059	-0.114
25/9/1994	34.886	3.294	2.044	-2.273	1.048	3.119	0.646	0.316	-0.063
26/9/1994	46.685	3.539	2.304	-2.098	1.297	3.387	0.921	0.601	-0.048
27/9/1994	58.583	3.744	2.520	-1.846	1.534	3.679	1.195	0.889	-0.071
28/9/1994	70.664	3.886	2.660	-1.548	1.730	3.960	1.430	1.148	-0.128
29/9/1994	83.013	3.923	2.691	-1.244	1.842	4.189	1.583	1.336	-0.205
30/9/1994	95.710	3.819	2.573	-0.957	1.827	4.316	1.613	1.406	-0.287
	Mean:	1.569	0.212	-1.257	-0.254	2.545	-0.424	-0.595	-0.195
	Rms:	2.323	1.818	1.383	1.444	2.711	1.351	1.324	0.330
	Max:	3.923	-2.699	-2.349	-2.578	4.316	-2.500	-2.499	-0.731
	Min:	0.080	-0.118	-0.362	-0.009	1.006	-0.009	0.059	-0.007

Planet: Jupiter
(Longitudes and Errors in Degrees)

Table 2. *Nirayana* longitudes of Jupiter for 30 days spanning over its own sidereal period of about 12 years. Column 2, gives the actual longitude (computed using modern methods) whereas the other eight columns give the error/deviation of the longitudes, as obtained using eight different texts, from the actual value. The last four rows give the mean, rms, maximum and the minimum value of the error obtained using that particular text.

Name of	the text	AB	KK	LM	SS	SI	GL	TS	SD
1/9/1982	192.520	6.343	3.113	6.541	3.800	6.785	2.551	0.379	-0.181
29/1/1983	222.484	5.691	4.081	-12.693	4.505	5.987	1.752	-0.201	-0.085
28/6/1983	218.883	7.601	4.891	19.243	5.516	8.322	3.214	-0.137	-0.104
25/11/1983	233.915	5.349	3.832	-7.306	4.075	6.304	1.615	-0.023	0.017
23/4/1984	259.248	6.232	5.882	-4.066	5.736	7.301	1.872	-0.417	0.236
20/9/1984	250.169	6.486	4.810	15.157	4.692	7.526	2.373	0.009	-0.032
17/2/1985	278.688	4.981	4.683	-11.589	4.210	6.159	1.049	-0.288	0.023
17/7/1985	290.678	7.389	7.358	9.341	6.374	8.604	2.590	-0.319	0.326
14/12/1985	290.964	5.593	4.939	1.154	4.248	6.588	1.586	-0.005	0.205
13/5/1986	323.777	5.210	5.757	-9.073	4.807	6.902	0.904	-0.473	0.314
10/10/1986	320.719	7.050	6.928	16.616	5.766	8.272	2.104	-0.563	0.275
9/3/1987	337.798	4.810	4.709	-6.999	3.855	6.080	0.616	-0.411	0.103
6/8/1987	5.728	5.759	6.433	-1.039	5.417	7.835	0.921	-0.834	0.389
3/1/1988	356.661	6.278	5.454	9.729	4.481	7.198	1.627	-0.304	0.185
1/6/1988	25.820	4.829	4.463	-8.549	3.779	6.158	0.561	-0.488	0.076
29/10/1988	40.510	7.058	6.158	7.647	5.361	8.155	1.633	-0.786	0.055
28/3/1989	39.027	5.539	3.920	-0.723	3.480	6.254	1.095	-0.334	-0.093
25/8/1989	71.003	5.580	4.287	-3.860	4.143	6.156	1.132	-0.316	0.184
22/1/1990	68.925	7.700	4.994	11.409	5.050	7.995	2.592	-0.346	0.125
21/6/1990	83.361	5.416	3.129	-4.963	3.340	5.776	1.416	-0.143	-0.094
18/11/1990	109.620	6.546	4.172	1.684	4.684	6.122	2.276	-0.323	0.003
17/4/1991	100.285	7.095	3.278	3.752	3.867	7.035	3.033	0.160	-0.201
14/9/1991	126.626	5.756	3.067	-2.481	3.678	5.553	2.098	0.122	-0.032
11/2/1992	138.203	8.116	4.369	7.128	5.374	7.198	3.901	0.050	-0.035
10/7/1992	137.409	6.095	2.589	-1.066	3.450	6.306	2.502	0.048	-0.282
7/12/1992	166.840	5.887	3.425	0.776	4.299	5.560	2.210	-0.227	-0.123
6/5/11993	162.000	7.863	3.792	4.587	5.067	7.970	3.468	0.012	-0.127
3/10/1993	177.940	5.744	2.972	-0.239	3.762	6.037	2.347	0.206	-0.096
2/3/1994	200.873	7.035	4.549	3.519	5.311	6.665	2.712	0.020	-0.074
30/7/1994	192.118	6.984	3.338	0.456	4.091	7.396	2.962	0.397	-0.312
	Mean:	6.267	4.512	1.470	4.541	6.873	2.024	-0.184	0.021
	Rms:	6.335	4.669	8.187	4.608	6.929	2.192	0.350	0.180
	Max:	8.116	7.358	-19.243	6.374	8.604	3.901	-0.834	-0.389
	Min:	4.810	2.589	-0.239	3.340	5.553	0.561	-0.005	-0.003

7 Concluding Remarks

1. Nilakantha Somayaji was perhaps the first astronomer in the history of astronomy to postulate the correct application of 'equation of centre' for the inner planets.
2. The overall picture of planetary motion in the Kerala school of astronomy at-least arrived by the time of Nilakantha (1500 AD) is as follows:
   (a) The five planets Mercury, Venus, Mars, Jupiter and Saturn go around the mean Sun.
   (b) The Sun along with the planets moves around the earth.
3. If a comparison were to be made with the developments of astronomy elsewhere:
   (a) Ptolemy treated Venus along with outer planets singling out Mercury. As most of the astronomers in Greek tradition followed Ptolemy, a clear separation of the inner and outer planets as found in the Indian tradition is absent in the Greek traditions.
   (b) Obviously the Ptolemy's model suffered from the improper application of 'equation of centre' in the case of inner planets.
   (c) The inaccuracies regarding the calculation of longitudes and latitudes of inner planets found in Ptolemy's model were not rectified by Islamic astronomers of later period or even by Copernicus and Tycho-Brahe (though they gave a different overall picture).
4. Nilakantha's work around 1500 AD, predates the work of Kepler by atleast 100 years, who seems to be the fist astronomer in the Greko-European tradition to have departed completely from the Ptolemiac scheme while giving his general theory of planetary motion.
5. The overall picture of planetary motion given by Samanta Chandra Sekhar around 1869 AD is not different from the picture given by Kerala astronomers or for that matter Tycho-Brahe in any respect. On the other hand the parameters given by Samanta for the calculations, based on his own observations with crude instruments, are very much different. It is quite interesting to note that these parameters used for the calculations of longitudes yield remarkably accurate results, when compared with the results obtained by other earlier texts on Indian astronomy (Refer Section 6].
6. It may be interesting and also informative to make a detailed study of the calculation of eclipses based on the text Siddhanta Darpana of Samanta because the value of Sun's parallax given in this text is far more accurate than any of the earlier Indian astronomical texts.



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Distances of Sun, Moon and Stars

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1 Sun

The Sun is our biggest neighbour in the cosmos. It is but natural to ask how far it is from us. The first attempt to determine Sun's distance was made by Aristarchus of Samos in the third century B.C. This was made possible from his observation that at half Moon the line joining the Sun and the Moon is at right angle to that joining the Earth and Moon shown in Fig. 1, below.

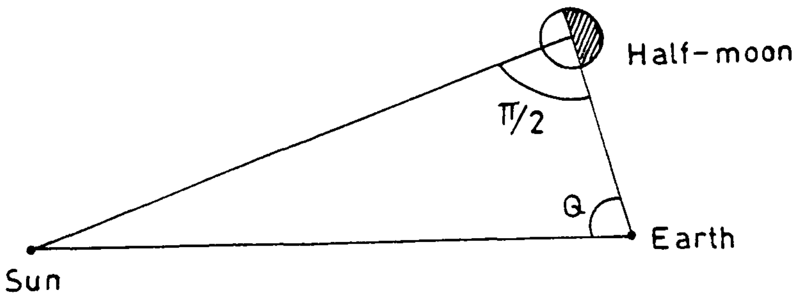


Fig. 1.

Measurement of the angel Θ would give the ratio of the distance of the Sun from the Earth to that of the Moon from the Earth. Aristarchus found this angle to be $\Theta = 87^0$. The ratio works out to

$$\frac{\text{Sun} - \text{Earth distance}}{\text{Moon} - \text{Earth distance}} = \frac{1}{Cos\Theta} = 20, \tag{1}$$

while the modern value for this ratio is 400. The large error arises from not knowing exactly when half-Moon occurs. Besides, the Sun and the Moon are not points. Aristarchus had to observe either their centres or edges.

Indian astronomers needed the distances of the Sun and Moon for use in the calculation of eclipses. Their measurements based on the angular velocities and use of some arbitrary numbers put the ratio (1) at about 14. Pathani Samanta was not happy with this number because he found that *Siddhāntas* written by famous ancient astronomers did not describe the scientific method by which they came to this figure.

One day he noticed Sun rays coming through a narrow aperture of the fence of palm leaves casting an image of the Sun on the wall. He thought he got the answer to the problem of measuring the distance of the Sun but soon realized that he needed the value of Sun's diameter. *Surya Siddhānta* gives this to be 6500 *yoganas* which is equal to 52000 Kms (1 *yojan* = 5 miles = 8 kms). Samanta was not satisfied with this. One day while reading Atharva Upanishad he found this to be 72000 *yojanas* = 576000 Km (Chapter 8, *Sloka 1*, *Siddhānta Darpana*). Using this value in his experimental observations he found the distance of the Sun to be (*Siddhānta Darpana*, Chapter VIII, *Sloka* 14)

$$d_\odot = 7608294 \ Yojana \ = 6 \times 10^7 Km, \tag{2}$$

as against the value

$$d_\odot = 1/50 \times 10^8 Km, \tag{3}$$

determined by modern astronomers.

Essentials of Samanta's experiment can be summarized as follows: Cast an image of the Sun on the floor of any other surface such as a wall by passing Sun's rays through a pin-hole. Bigger hole will cast a brighter shadow but not bigger. If the hole is too big there will be no image. Ratio of the size of the image to the distance of the surface from the pin-hole gives the ratio of Sun's diameter to its distance. (Fig. 2).

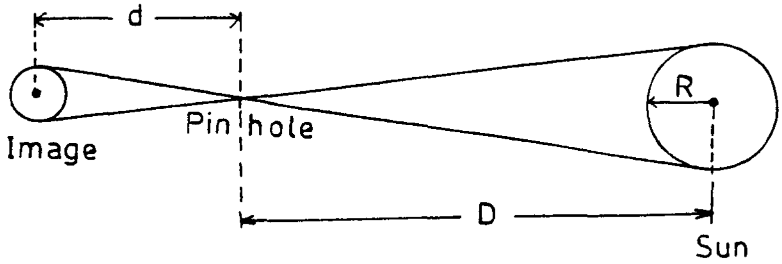


Fig. 2.

$$\frac{r}{d} = \frac{R}{D} = 96. \tag{4}$$

Pathani Samanta uses a formula that contains pine-hole's diameter from which he obtains the ratio to be 96. (Chapter 19, *Shlokas* 62-64. *Siddhānta Darpana*).

A variant of this experiment can be performed with a coin. Fix the coin to a window grill and view it with one eye and adjust your distance from the coin till the coin just blocks out the Sun (Fig. 3). The ratio of the coin diameter and the distance

of your eye from it, equals the ratio of Sun's diameter to its distance. It is found that

$$\frac{d}{D} = \frac{r}{R} = 108. \tag{5}$$

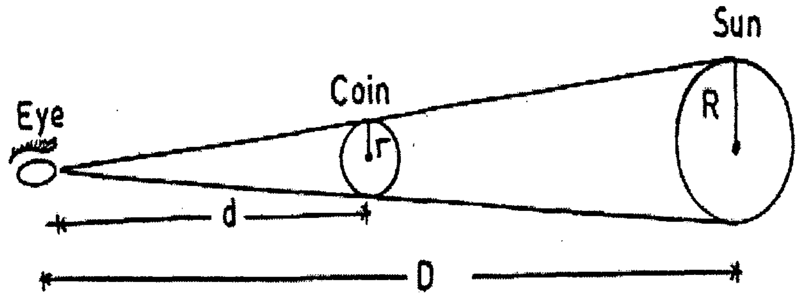


Fig. 3.

Apart from its use in calculation of eclipses, the Sun-Earth distance is important for another reason. All distances of the solar system, as well as the distances of stars are expressed in terms of this distance which is taken as a unit of distance called the astronomical unit (AU). It is related to Sun's geocentric parallax P. For a celestial body, it is defined as the angle subtended at it by a known distance. In the case of the Sun, Moon or a planet this distance is taken to be the radius of the Earth. To determine the parallax, one measures the apparent angular displacement of the body when viewed at a given point on Earth's surface and then from another point.

From Fig. 4 one finds that the horizontal parallax is given by

$$\sin P = \frac{R_\oplus}{d_\odot}, \tag{6}$$

where the symbols $\odot$ and $\oplus$ stand for the Sun and the Earth. The measurement of apparent displacement is made with reference to a star near the celestial body. In the case of the Sun this cannot be done since stars are not visible when the Sun is out. This method can, however, be adopted during a solar eclipse which does not occur often. It is therefore necessary to resort to the indirect method of measuring the parallax of some planet or asteroid, obtain its distance and then use Kepler's law which states that

$$\frac{(Period)^2}{(Mean\ distance\ from\ the\ Sun)^3} = Constant\ for\ all\ planets \tag{7}$$

to obtain mean distance of the Sun from the Earth. Extensive measurements on the asteroid EROS over a period of ten years with 2847 photographs taken with 30

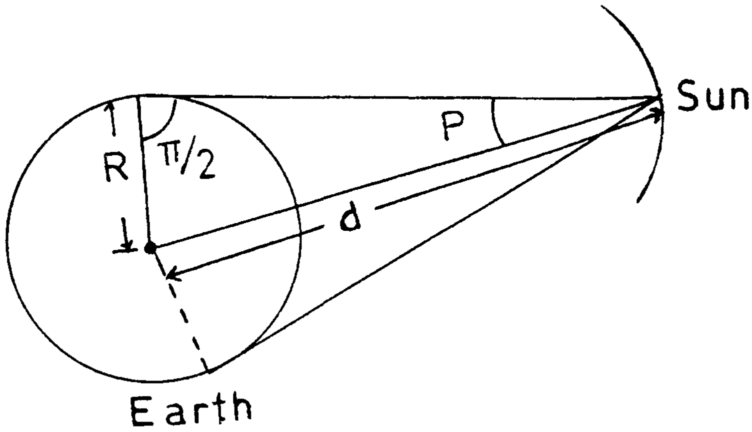


Fig. 4.

different telescopes in 14 countries gives

$$P_\odot = 8.794 \pm 0.002 \; arc \; seconds, \tag{8}$$

from which the Earth-Sun distance is calculated to be

$$1AU = 1.495985 \times 10^8 Km. \tag{9}$$

Most modern and accurate value is obtained my measuring the distance of a planet or asteroid by time delay or radar reflection.

Another method of determining the Sun-Earth distance is by the measurement of aberration of light. On account of motion of the Earth on its orbit around the Sun, direction of light coming from a star shifts, necessitating a tilt of the telescope by an angle $\ominus$ given by

$$\tan \ominus = \frac{v}{c}, \tag{10}$$

where $v=$ velocity of the Earth and $c=$ velocity of light. To understand how this occurs, consider the case of a bullet fired at a car at right angles to its direction of motion. It will hit the moving car at an angle $\ominus$ as shown in Fig. 5 where

$$\tan \ominus = \frac{v_{\text{car}}}{v_{\text{bullet}}}. \tag{11}$$

Exactly the same thing happens to light coming from a distant star entering a telescope on the Earth. This phenomena was first observed by Bradley in 1725 A.D. providing experimental evidence for motion of the Earth in an orbit around the Sun. Accurate measurements give

$$\ominus = 20.496 \text{arc. sec}, \tag{12}$$

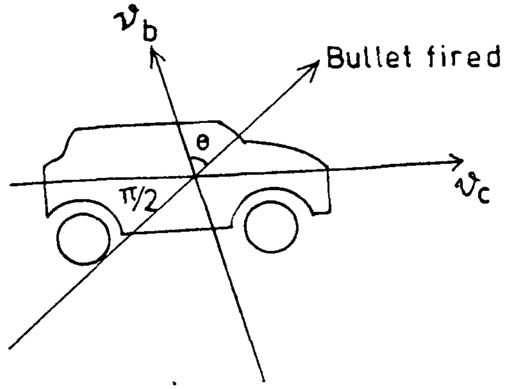


Fig. 5.

from which velocity of the Earth is obtained by using (11) replacing v_{car} by v and v_{bullet} by c as

$$v = 29.80 Km/Sec. = 10728 Km/hr. \tag{13}$$

Assuming circular orbit for the Earth, one finds the perimeter (distance moved in one year) to be

$$2\pi d_{\odot} = 9.93 \times 10^8 Km, \tag{14}$$

which gives $1AU = d_{\odot} = 1.49 \times 10^8 Km$. The solar parallax obtained from (10) is

$$P_{\odot} = \frac{R_{\oplus}}{d_{\odot}} = \frac{2\pi R_{\oplus}}{kcT}, \tag{15}$$

where $k = \tan\ominus$ is the aberration constant and $T=$ time period of Earth's motion which is 1 year. Taking ellipticity of the Earth's orbit into account, (15) becomes

$$P + \odot = \frac{2\pi R\oplus}{kcT\sqrt{1-e^2}}, \tag{16}$$

where $e=$ ellipticity $= 0.01674$. It is worth mentioning here that solar parallax was calculated by Indian astronomers from the rate of the motion of Sun which was assumed to be revolving around the Earth. The results were far off the mark.

2 Moon

The Moon is our nearest neighbour in the cosmos. It is unfairly dubbed as a satellite of the Earth. Actually it is not so small compared to Earth as satellites of other planets in our solar system. For determining its distance from the Earth, one has to measure its geocentric parallax. This is done by two observers sighting the same point

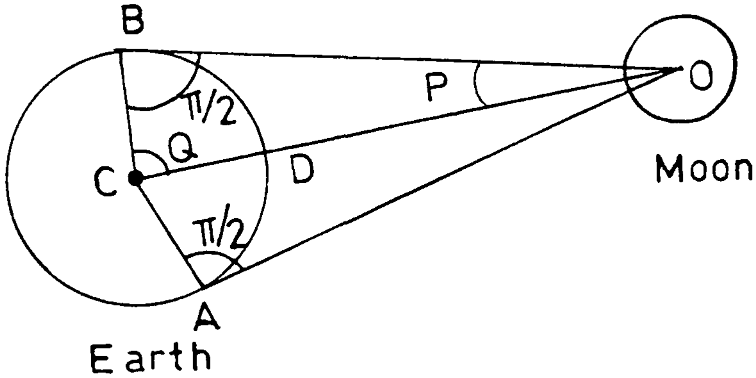


Fig. 6.

on the Moon from two positions A and B on Earth, at the moment it is rising at A and setting at B as shown in Fig. 6.

It is clear that

$$P = \frac{\pi}{2} - \Theta, \tag{17}$$

$$\Theta = \frac{BD}{R_{\oplus}}. \tag{18}$$

Hence, once the distance between the two observers and the radius of the Earth are known, Moon's geocentric parallax can be calculated using (17) and (18). It is to be noted that this parallax varies from day to day (which is equivalent to saying that Moon's distance varies). Further, Moon is a big object and therefore the parallax will vary depending on the point on the Moon that is observed. Measurements yield for the Moon's equatorial horizontal parallax:

$$P = 57'2.7''. \tag{19}$$

This means Moon's mean distance is 60 times Earth's radius:

$$d = 3.844 \times 10^5 Km. \tag{20}$$

Indian astronomers had obtained the values recorded in the *Siddhāntas* as follows

$$\begin{aligned} &\textit{Surya Siddhānta}: \ 53'20'', \\ &\textit{Sidhānta Siromoni}: \ 52'42'', \end{aligned} \tag{21}$$

where as Pathani Samanta's result is closer to the modern value

$$\textit{Siddhānta Darpana}: 56'28'', \tag{22}$$

which corresponds to a distance

$$d = 3.89 \times 10^5 Km. \tag{23}$$

Since the advent of radar, laser methods and lunar probes, including lunar artificial satellites, Moon's distance can be measured very accurately.

3 Stars

For the measurement of distances of Sun and Moon, astronomers measure their geocentric parallax for which the base line is Earth's radius. Stars being very far, adoption of this as base line would make the parallax very very small. One therefore adopts Sun-Earth distance (which is defined to be one astronomical unit) as the base line. The stellar parallax is defined (Fig. 7) as

$$p = \frac{1AU}{d}, \tag{24}$$

where d=distance of the star.

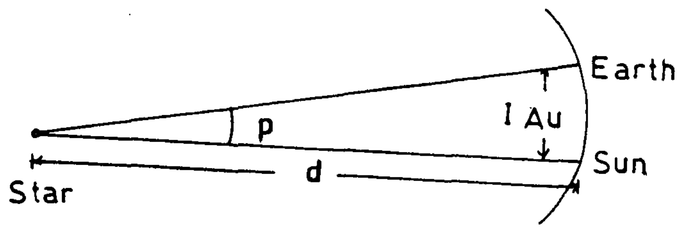


Fig. 7.

Since p is very small (about one thousandth of a degree), it is measured in arc seconds.

In that case, one has

$$d = \frac{206265}{p''} AU. \tag{25}$$

This tells that a star with a parallax of 1″ is 206265 AU away.

Measurement of the parallax of a star is made by taking photographs of a star's image in a telescope at six month's intervals when the Earth is at E_1, E_2 and E_3 as shown in Fig. 8 below.

The rays entering the telescope for the corresponding observations are shown in Fig. 9 and the position of the image on the photographic plate in Fig. 10.

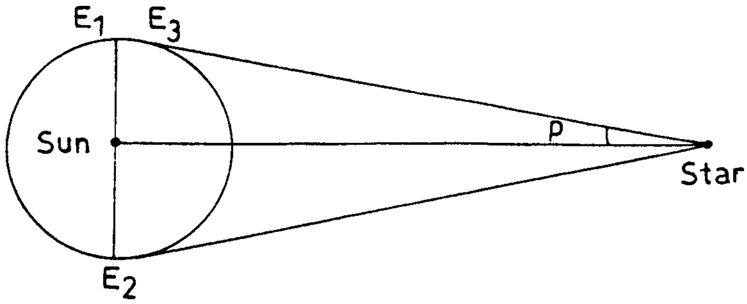


Fig. 8.

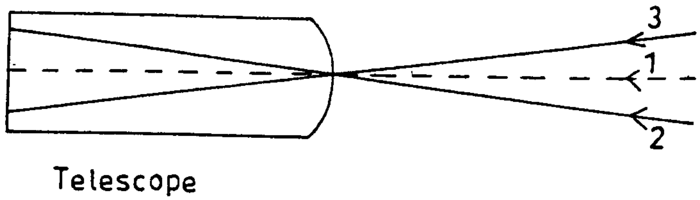


Fig. 9.

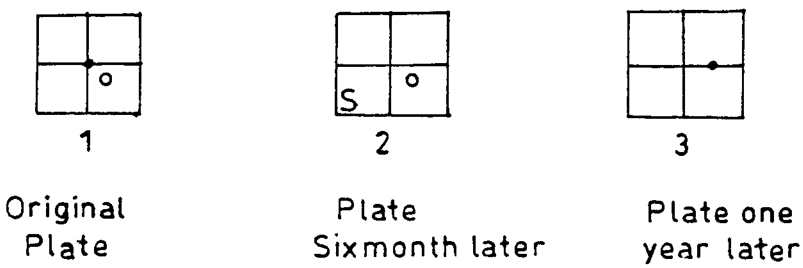


Fig. 10.

Distance OS on the plate divided by the distance of the plate from the telescope objective gives twice the parallax. If the position of the star one year after, is not the same as the original position, a correction has to be made taking this into account. Actually for accuracy five or more photographs are to be taken.

It will be seen from Fig. 8 that a fixed star viewed from two positions from the Earth, i.e. in different months of the year, shifts position. The Danish astronomer Tycho Brahe rejected the Copernican theory because he could not detect any parallactic shift of stars with the aid of his naked eye instrument. The same is true of Pathani Samanta. It was in 1857 that Bessel, using the Koenisberg heliometer detected parallactic shift of the star 61 Cygni and measured the angle and found it to be

$$p = 0.31 arc\ sec., \tag{26}$$

which correspond to a distance of

$$d = 687550 AU. \tag{27}$$

The following year Henderson in South Africa measured the parallax of the star Alpha Centauri using the ordinary mural circle and obtained

$$p = 0.75 arc\ sec. \tag{28}$$

and its distance

$$d = 275020 AU. \tag{29}$$

Struve in Russia measured the parallax of Vega in 1840 using filar circle and found it to be

$$p = 0.13 arc\ sec. \tag{30}$$

from which he obtained

$$d = 158653 AU. \tag{31}$$

Because of largeness of distances (smallness of parallax) of stars, a new unit of distance called "parsec" is used. It is the distance of a celestial body whose parallax is one arc second. Calculation gives

$$1 parsec = 206265 AU = 30.86 \times 10^{12} Km \tag{32}$$

$$= 3.26 light\ year, \tag{33}$$

where one light year is a distance travelled by light in one year and found to be

$$1\ light\ year = 9.46 \times 10^{12} Km$$

The stellar parallaxes measured by Bessek, Henderson, Struve and many others were not very accurate. Parallaxes of the same star measured by different observers and different instruments disagreed. Use of photography, better heliometers and meridian circles during the latter part of 19th century and early 20th century did not improve

the situation very much. In 1901, Kapteyn published a list of parallaxes of 53 stars, and Weersma gave parallaxes of 365 stars most of which were determined visually. A new era in photographic measurement of stellar parallaxes was started by Schlissinger in 1903 using the 40″ refracting telescope of the Chicago University's Yerkes Observatory. In 1924 he published the "General Catalogue of Stellar Parallaxes" containing parallaxes of 1870 stars. Its 1952 edition compiled by Jenkins contains parallaxes of 5822 stars based exclusively on photographic measurement. This program was later extended by several observation around the world.

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Siddhāntic Astronomy

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1 Introduction

Study of astronomy in India has been one of the major intellectual pursuits in its long history and is the gift of India to the present world. India has a continuing tradition in astronomy since the Vedic period [1]. The Hindu Pancanga pervades through the daily life of the people. The study of heavenly bodies is called Jyotish Shastra. It has three components:

1. ***Ganita*** deals with reckoning of time (i.e. *Kālakriyā*) and spherics (i.e. Gola) treating positions and motions of Earth, planets and asterisms with the help of models and the astronomical instruments.
   In *Kālakriyā* (or in a separate section) various astronomical constants related to the motion of heavenly bodies are enumerated. Various mathematical algorithms about obtaining the their accurate positions at any given time, their conjunctions and other such topics are dealt within *Kālkriya.*

   In Gola the concepts in astronomy are sharpened by making toy models. Various instruments are described for observation.

   For astronomical predictions, the relative motion of heavenly bodies needs to be observed at any given instant of time. Therefore the measurement of angular positions of the bodies with respect to suitable reference axes are recorded along with the record of time. Such observations are recorded over a number of years. These are then described in the form of processed information in the texts. The differences from era to era are observed by succeeding astronomers who refine the predictability of the planetary positions by improving mathematical techniques, finding out further corrections and so on. At a given instant of time positions of various planets can be calculated based on Ganita and a horoscope can be prepared. The horoscope is purely a diagrammatic representation of planetary positions and is therefore an astronomical record.
2. ***Jātaka*** deals with horoscopes of various persons prepared on the basis of Ganita taking the instant of time as the time of birth. Future is predicted based on the relative positions of planets. This is what most people are interested in and whenever the word "*Jyotisa*" is mentioned, the immediate reaction is to think of the speculative subject of astrology rather than the exact science of *Ganita* or astronomy.

3. ***Śakha*** deals with the predictions on the basis of planetary positions for good or bad effects on the world, the rains and the unusual phenomena perceived in nature.
   It can therefore be called natural astrology in contrast to *Jātaka* or *Horā* which is human astrology.

The evolution of the Indian astronomy can be classified into following periods -

1. the Vedic Period (3000 BC - 1400 BC),
2. the *Vedānga Jyotisha* Period (1400 BC - 100 BC),
3. the *Siddhānta* Period (100 BC - 1900 AD) and
4. Modern Period (1800 AD -).

The Indian *Jyotish Shastra* developed from Vedic period onwards. There are several descriptions of astronomical observations scattered in the Vedic literature. At some time some of these were summarised in *Vedanga Jyotisa*. Post-Vedic literature consisting prominently of *Purāns*, deals with several aspects of astronomy and cosmology in the description of the available traditional knowledge in the form of stories. All *Purānas* do not belong to the same period, and some of them were composed just after the Vedas. Many of the *Purānas* have description of the units of time and have long time periods of yugas, *Caturyugas, Kalpa* and *Brahma's* life. Out of these *Vishnu-dharmottara Purāna* is supposed to have the material on which some of the later astronomical texts were based.

There has been a long-standing controversy about the chronology of the Vedic and post-Vedic literature. The chronology generally accepted in the West is that of Max Muller dating Rigveda to 1200-100 BC affecting the dating of the earlier astronomical literature. Kak [2] dates *Brāhmana's* (which are post-Vedic) to 2000-1000 BC unambiguously based on the analysis of an altar described in *Śatpatha Brāhmana*. This placed the Rigvedic astronomy around 4000-2000 BC, *Brāhmana's* astronomy around 2000-1000 BC and earlier Siddhantic astronomy around 1000 C - 500 AD. Earlier it was believed that *Mahāyuga* of 4,320,000 years was borrowed from the astronomy of the Babylonian Berossos (around 300 BC), but it already occurs much earlier in Śatpatha Brāhmana (around 2000-1000 BC).

Cultural exchanges between Greeks and Indians became intense around the period of Alexander the Great. This brought in Babylonian-Greek elements in Indian Astronomy. Seven-days'-week system and twelve *rashi* division of the ecliptic are believed to come into use along with the 27 nakshatras enumerated in Atharvaveda. Though twelve *rashis* automatically follow 12 months in the year and they can very well be Indian in origin, however, the *rashi* names are translations from the corresponding ones in Greek astronomy.

The present day texts in sciences borrow heavily from the Western traditions and do not emphasize the Indian contributions from the ancient and medieval periods. I am very glad that this symposium is dedicated to the memory of the great Indian astronomer Samanta Chandra Sekhar who was born in Orissa in 19th Century. He

is the last great astronomer in the long tradition of *Siddhāntic* astronomers of our country.

David Pingree [3] quoted in ref. [1] has carried out a 'Census of the exact sciences in Sanskrit' at the American Philosophical Society, Philadelphia during 1970-1981. He states "At present there exist in India and outside of it some 1,00,000 manuscripts on various aspects of *Jyotihaśastra.* The great majority of these were copied within the seventeenth, eighteenth and nineteenth centuries; for the manuscripts cannot survive in India except under exceptional circumstances. We have, therefore, essentially those texts selected for study composed by scholars of the Mughal and British *rajyas.* Since the copying of manuscripts is virtually dead in Modern India, many of these estimated 1,00,000 manuscripts will soon disappear and the possibility of achieving a reasonable assessment of the continuity, development, and transformation of the astral and mathematical sciences in India, will be correspondingly diminished."

The Indian National Science Academy has a continuing programme in this field. Vishveshwaranand Institute, Hoshiarpur also promoted this activity and especially emphasized Kerala-based astronomy and astrology. Further there seems to be communication gap between the traditionally trained Indian astronomers through Sanskrit and other Indian languages, and the scientists trained through the present system of education like me who do not know their heritage in this area well. It is possible that a proper understanding of the earlier Indian methods may lead to improvements in the orbit calculations in present day space physics.

2 Siddhānta Texts and Prominent Astronomers

The Siddhānta texts are in the nature of rules or the method of solving the concerned astronomical problems. The texts dealing with astronomy in Siddhānta period can be classified in four categories.

1. **Siddhānta** are the works which deal in detail with planetary positions and other astronomical topics with reference to the beginning of the creation for calculations. The computations involve large numbers. the Siddhānta are primary texts on which further calculations can be based.
2. ***Tantras*** deal with astronomical computations with reference to the beginning of *Kaliyuga.* They give simplified and short rules for computations.
3. ***Karanas*** deal with computations with reference to the time of composition as the epoch for calculations. They can be considered as manuals for preparing the calendar or the *Pañcanga.* The writer of the *Karana* has to be well versed with Siddhāntas and he makes the computations tractable and simpler.
4. ***Vyākhyās*** **or commentaries** - All the three *Siddhāntic* texts are often obscure or just meant for memorizing. They are to be supplemented with commentaries and illustrations which improve comprehension and can be considered as text books to teach the *Siddhāntic* texts

Original or improved concepts can be available in any of the four texts. Therefore all the four types of texts are to be studied to get a proper feeling about the Indian

astronomy. The observational astronomy needs the use of instruments while the mathematical astronomy needs development of various concepts, mathematical techniques, their application in numerical analysis of the observed data to obtain astronomical constants and the planetary models.The prominent Siddhāntic astromomers [4] are listed in Table 1.

Table 1. Prominent Astronomers of *Siddhāntic* Period

Period	Name	Text(s) written
4th-10th Century AD	Mayāsura (not a definite author)	Sūrya-siddhānta continually upgraded
5th-6th Century AD	Āryabhata I	Āryabhatīya†
		Āryabhata-siddhānta
6th Century AD	Varāhmihira	Pañca-siddhāntika
6th-7th Century AD	Bhāskara I	Mahābhāskariya
	Brahmagupta	Brahmasphuta-siddānta
		Khandakhadkya
8th-9th Century AD	Lalla	Śiśyādhi-vrddhidā-tantra
10th Century AD	Vatésvara	Vateśvara-siddhānta
	Munjala	Laghumānasa
	Āryabhata II	Mahāsiddhānta
11th Century AD	Śrīpati	Siddhānta-śekhara
12th Century AD	Bhāskara II	Siddhānta-śiromanī
15th Century AD	Parameśvara	Goladīpikā etc.
	Nīlakantha Somayāji	Tantra-sangraha
16th Century AD	Ganeśa Daivajna	Grh-lāghavam
18th Century AD	Rājā Jaisimha	Yantrarajaracana
	Jagannath Samrata	Samrātasiddhānta
19th Century Ad	Sāmanta Chandraśekhara	Siddhānta-darpana

† Translated in Arabic in 8th century AD.

Major *Siddnānta* texts are listed. By assimilation of various ideas, 18 *Siddhāntas* became prevalent by 5th century A.D. [1,p,xxiii]. Varāhmihira (AD 505-587) compiled five out of them in his *Pañca-siddhāntikā* namely the *Saura* (surya), the *Paitamaha*, the *Vaśistha*, the *Romaka* and the *Pauliśa*. The *Surya Siddhānta* available in the present form [5] seems to evolve right from 4th century to 10th century and therefore it is not written by a single author. At times its authorship has been attributed to Āryabhata I or his disciple Latadeva. Āryabhata I [6, 10] is the prime astronomer of the Siddhāntic period who composed the treatise Aryabhatiya [8] in AD 498. Āryabhata I heralded the beginning of the modern astronomical revolution in India as well as in the world. The Ācārya, as Āryabhata is often called, was criticised by his successors in his process of departing from Purānic literature, by Varāhamihira and Brahmagupta. After Āryabhata I, there was continuous development of Siddhāntic astronomy upto

1150 AD when Bhāskara II wrote his treatise Siddhanta-siromani. The contributions by Brahmagupta in 628 AD are available in *Brahmasphuta-siddhanta* where he gave improved rules for the planetary calculations. Though he is very critical of Āryabhata I in this work, he composed the Karana text *Khandakhādyaka* in 665 AD based on Āryabhata's *ardharātrika* (midnight) system. Lalla wrote an important Tantra called *Sisyadhi-vrddhidā tantra.* Following Āryabhata I, Bhāskara I (c 600 AD wrote *Mahābhāskariya, Laghubhāskariya* and a commentary [10] on Āryabhatiya. He further elaborated the indeterminate analysis.Vateśvara (b 880 AD) wrote his *siddhānta* and *Manjulā* (c 932 AD) wrote the Karana text Laghumānasa. Both described the precession of equinoxes. Śripati wrote *Siddhānta-śekhara* having 20 chapters. He considered the second inequality of moon. Bhāskara II wrote an excellent text *Siddhānta-śiromani* consisting of four parts *Līlāvatī, Bījaganita, Grhaganita and Golādhyāya.* Out of these the latter two deal with astronomy. Ganeśa Daivajñ of Nandigrama, a place 65 km from Mumbai wrote the Karana text Grh-lāghavam in which the trigonometrical calculations were avoided and simpler arithmetical methods were introduced. In Kerala, astronomical studies continued till 18th or 19th century. Prominent Kerala astronomers are Mādhava (c 1340-1425 AD), Parameśvara (c 1380-1460), Nīlkantha Somayāji (c 1444-1550 AD) and Acyut Piśārāti (c 1550-1621). The Indian siddhantic literature has therefore astronomy, based on Āryabhata I i.e. *Ārya-Siddhānta*, the one based on Brahmagupta i.e. *Brahma-Siddhānta* and the one based on *Sūrya-Siddhānta.* These systems are very similar to one another. In Table 2 prominent siddhanta texts are listed along with number of verses in them. The text of Sāmanta Chandra Sekhar [11, 12] is the biggest one.

3 Observational Astronomy

The astronomical observations are given the highest priority in the Indian astronomy. Mathematical astronomy was based on the previously recorded or described informaton and the current observations. Though the mathematical astronomy is available in the *Siddhāntic* texts, the observations are not described in them in detail. Primary records of observation are not available and only derived quantities are given in the texts.

Many instruments are described in a very sketchy manner in the treatises of *Siddhānta* Period. Predictions for future period were carried out using the known principles. Discrepancies with observations were noted, and to improve the situation, either further corrections were worked out, or the principles and the mathematical framework were improved. Observations made in one reference era may not yield accurate results at some other distant point in time, as the astronomy described the motion of heavenly objects specifically the fast moving ones i.e. the planets including the Sun as a function of time phenomonologically.

Āryabhata I described Gola Yantra i.e. automatic sphere. It is given similar movement as that observed of the stellar objects from earth. We should realise that for gettring accurate results on planetary astronomy, one need not have very accurate

Table 2. Prominent Siddhantic Texts and their Verses

Date	Author	Treatise	Acronym	No. of Slokas
400-1000 AD	Mayāsura	*Sūrya-Siddhānta*	SuSi	500
498 AD	Āryabhata I	Āryabhatiya	Abh	13 + 108
628 AD	Brahmagupta	Brahmasphuta -Siddhānta	BrSpSi	1008
768 AD	Lalla	Sisyādhi-vrddhidā-tantra	SiDVr	322
904 AD	Vateśvara	Vateśvara - Siddhānta	VSi	1326
1039 AD	Śripati	Siddhānta Sekhara	SiSe	890
1150 AD	Bhāskara II	Siddhānta -Siromani	SiSi	460
1500 AD	Nilakanta Somayāji	Tantra -Sangraha	TS	431
1869 AD	Sāmanta Chandrasekhara	Siddhānta -Darpana	SiDa	2284+216

direction measuring device having the telescopic magnification. Other measurement is that of time which is very easy to achieve with the available clocks in modern times. Earlier primitive forms of clock were in use.

Bhāskara II [13] says that for learning about the finer details of the motion of astronomcal bodies, instruments are needed. These are

1. *Gola Yantra*
2. *Nādivalaya*
3. *Yasti*
4. *Śanku*
5. *Ghati*
6. *Cakra*
7. *Cāpa*
8. *Tūrya*
9. *Phalaka* and
10. intelligence.

His predecessors Brahmagupta and Lalla have also described instruments of similar type. Modern Sūryasiddhānta also carried a chapter on instruments. All the astronomical observations are made from a particular place on earth and its properties such as geographical longitude and latitude are also determined. According to Lalla [14] the hypoteneuse (*karna*), the semiduration of the day, (the longitude of) the

Sun, the latitude (of the place), the plumb, the compass (*bhrama*), water, as well as intelligence and effort are the things required in the use of astronomical instruments.

Through his perseverance Samanta Chandra Sekhar [11] made extensive observations with the instuments fabricated by him. His *māna-yantra* which is a very versatile instrument is basically a tangent staff for measuring angles. He found several discrepancies between the observed planetary positions and the calculated ones based on the available *Siddhāntas*. He improved the astronomical constants and described his work in the exhaustive text *Siddhānta Darpana.*

There existed astronomical observatories which have disappeared with the advancing arrow of time. An observatory is described to have existed around AD 878 in Kerala [1, p.8]. The observatories built by Rājā Jayasimha in early 18th century exist even now in Delhi, Jaipur, Ujjain and Varanasi. Astronomical records were prepared. These are not fully analysed.

4 Mathematical Astronomy

The power of Indian astronomers' works lies in their skill in arithmetical and algebraic techniques. India has been the mother of the arithmetical techniques and the decimal number system together with the nine numerals and the most precious "zero". The Greeks could be considered better than Indians only in geometrical techniques. Even here the Śulbsūtras [15] written by Baudhāyan (500 BC), Mānava (400 BC), Āpastamba (300 BC) and Kātyāyana (250 BC) form part of Vedāngas called *Kalpa* and indicate that Indians had good knowldege of geometry. The Pythagoras' (c. 540 BC) theorem is given by Baudhāyan. Even after the modern European astronomers developed astronomy, they were very restricted in its development even in 19th century as Robert W. Sinnott (in 1990, Cambridege, Massachusetts) in his forework to 'Astronomy on the Personal Computer' by Montenbruck and Fleger [16], states that "It is said that a typical astronomer of the 19th century spend seven hours at a desk for every hour spent at the telescope. That's how long the routine analysis of data took with pencil, paper and logarithmic tables. Thus when Wlhelm Olbers discovered the minor planet Vesta in 1807 and gathered the necessary observatio0ns, his friend Gauss needed almost 10 hours to hand-calculate its orbit. That achievement astonished many less gifted astronomers of the time, who might have laboured days to work out the orbit of a newfound comet."

This should also restrain people from making unrestrained remarks that everything gets accomplished in Europe through the Copernican heliocentric hypothess, Tyche Brahe's observatons, Keplerian analysis and Newtonian law of Gravitational attraction plus the observations made using the telescope. Too much glorification has been done of these celebrities by projecting it as a conflict of the Ptolemic geocentric and Copernican heliocentric models. European schloars copied a lot of Indian techniques without giving due credit to the Indian astronomers and mathematicians. The type of capacity of earlier Indians in handling numbers is available to scientists now with the development of the computing power of the personal computers.

4.1 Mathematical Techniques

4.1.1 Unit: The proper definition of various units and subunits of time and angles has been described by most of the Indian astronomers. Various units of time ranging from microseconds to 10^{14} years aer described in the texts. *BrSpSi*, *VSi* and *SiSi* give the following units of time-divisions

$$
\begin{aligned}
\text{Lotus pricking time} &= 1\ \textit{truti} = 8.889 \times 10^{-6} \text{ seconds} \\
&\cdots \\
4.5 \times 10^{5}\ \textit{trutis} &= 1 \text{ asu} \\
&\cdots \\
(1 \text{ asu} &= 4 \text{ seconds}) \\
6 \text{ asu} &= 1 \text{ pala} \\
60 \text{ palas} &= 1\ \textit{ghatika} = 24 \text{ minutes} \\
60\ \textit{ghatikas} &= 1 \text{ day} \\
30 \text{ days} &= 1 \text{ month} \\
12 \text{ months} &= 1 \text{ year} \\
4.32 \times 10^{6} \text{ years} &= 1\ \textit{yuga} \\
72\ \textit{yugas} &= 1\ \textit{manu} \\
14\ \textit{manu} &= 1\ \textit{kalpa} \\
2\ \textit{kalpas} &= 1 \text{ day-night of } \textit{Brahmā} \\
&= 8.709 \times 10^{9} \text{ years} \\
360 \text{ day-nights of } \textit{Brahmā} &= 1 \text{ year of } \textit{Brahmā} \\
&= 725{,}760\ \textit{yugas} \\
&= 3.315.. \times 10^{12} \text{ years} \\
\text{life of } \textit{Brahmā}\ (1\ \textit{mahakalpa}) &= 100 \text{ years of } \textit{Brahmā} \\
&= 7.2576 \times 10^{7}\ \textit{yugas} \\
&= 3.135.. \times 10^{14} \text{ years}
\end{aligned}
$$

4.1.2 Alphabetical System of Numbers: As most of the texts in Siddhāntic astronomy are written in verses, it was very useful to have alphabetical number systems where words represented the numbers. the following number system are encountered

1. **Bhūta sankhya notation**[1]-
   This was used by Varāhamihira, Brahmagupta, Bhāskara I and II and in Sūrya Siddhānta. Several words have numerical connotations. For example the vedas aer four in number, therefore veda means four. Khabanasuryaih is kha+bana+surya. Kha, bana and surya have values 0, 5 and 12 respectively. This work is read from right to left and therefore stands for 1250.
2. **Āryabhatiya number system**[9]-
   In the first part of Āryabhatīya, known as Dasgītikāpāda there are 13 verses composed in *gītika* meter. In this part, Āryabhata I described an alphabetical number system in which numbers can be represented very compactly in words. The 25 varga consonants of the Devangari alphabet starting from *ka*, *ca* (like in

chair), *ta, ta*(soft) and *pa vargas* are given value 1 to 25. The avarga consonants have the values given in small brackets after them as *ya*(30), *ra*(40), *la*(50), *va*(60), *sha*(70), *sa* (like a mist) (80), *sa* (like in sat) (90) and *ha* (like in has) (100). When a vowel is added to a consonant, its values increases in multiples of 100. Short and long vowels are treated on same footing. The vowels have the values a (1), i(100), u(10,000), r(1,000,000) and l(100000,000). When compound consonants are used, the two consonants are first added and then the value of the vowel is multiplied. For example *Khyughr* is having the value $(2 + 30) \times 10^4 + 4 \times 10^6 = 4.32 \times 10^6$. So in few verses the tables of astromomical constants are described. However, this number system, Āryabhata, does not use in other parts of Āryabhatya.

3. **Katapayādi system** [1, 17]-
   This system is described as commonly used in South India. It is used by Āryabhata II as 'The consonants are starting from *ka, ta, pa* and *ya* represent numerals from one in succession in the order of the consonants; na and na denote zero. The chronogram when separated from each other have *a* and *ai* at their end in the nominative (plural) and in the instrumental (plural) respectively.' Here the half letter or addition of vewels does not change the numerical value of the consonant. In a *kalpa* Āryabhata II gives '*ghadaphene nnanuneenah*' years standing for 432,000,000 years. This is read from left to right. There exist *katapayādi* words read the other way as wells.
4. **Aksharapallǐ system** [10, p.c]-
   This system is described by Śankaranāyana (10th century). Here *na, nna* and *nnna* or *nya* or *nnya* stand for 1, 2 and 3. Following combibations stand for the numbers in paratheses - *ska* (4), *jhra* (5), *hā* (6), *gra* (7), *pra* (8), *skro* (9), *ma* (10), *tha* (20), *la* (30), *pta* (40), *ba* (50), *tra* (60), *tru* (70), *ch* (80), *na* (90), and *ña* (100). Reading from left to right '*nna tha nna nnna*' stands for 22023 while reading from right to left 'skra na pra pra pra hā hā skra nya' stands for 346,688,814.

Recently Srivastava [18] has described a **phonetic number code** with the base of 128. In this system 16 consonants and 8 vewels from Indian alphabets have been used. The consonant c with vowel v has value $8 \times (c - 1) + (v - 1)$ where the serial number c is in increasing order for k, g, c, ch, j, t, th, d, n, p, b, m, r, l, s and h starting from 1 to 16 and the vowel serial number is a, a, i, u, e, ai, o and ou from 1 to 8. Therefore da li ki is having numerical value 57 106 2 in base 128. So every number going from right to left gets multiplied by its place value p by 128^{p-1}. 'da li ki' stands for 947458. This code has been used to obtain multipurpose identification system for Indian citizens. Nine phnetic digits go to 19 digits in decimal system. This code can be easily stored on the computers as its uses a multiple of the binary base.

4.1.3 Value of π: The value of π is a very important constant for astronomical as well as other mathematical calculations. Sūrya Siddhānta and Brahmagupta used the value of π as the square root of 10. Aryabhata I gives the value of $\pi = \frac{62832}{20000} = 3.1416$. It is the most accurate one known at his time. Vateśvara, Bhāskara II and Sāmanta

Candra Sekhara have also used the Āryabhata's value of π. Of course Bhāskara II also gives the approximate value 22/7. In the book on Vedic Mathematics, Śankarācārya of Puri gives [17] a verse in *anustup* metre. This gives $\frac{\pi}{10}$ accurate to 32 places of decimal. It is to be read as per the left to right *katapayādi* system ignoring half letters. The value of 0.31415926 53589793 23846264 33832792. *Anustup* meter is having four stanzas of 8 letters each. Here the numbers are clubbed per stanza.

4.1.4 Trigonometry and other mathematical techniques: Āryabhata I gives a table of R sine differences in one verse. R is chosen so that the angle in minutes is equal to R sine for small angles. Using the relationship $\sin\theta = \theta$ for small values of θ, θ being measured in radians, we get $\frac{\theta\times 60}{\pi} R\sin\theta = R\theta$ or $R = \frac{60\times 180}{\pi} = 3438$. Āryabhatiya gives the verse as [1, p.62]

'The R sine differences (at interval of 225 minutes of arc) in minutes of arc are 225, 224, 219, 215, 210, 205, 199, 191, 183, 174, 164, 154, 143, 131, 119, 106, 93, 79, 65, 51, 37, 22 and 7.' (Abh 1.12)

The deduced R sines along with modern values are listed in Table 3 [6].

Table 3. R sines of angles

θ	Indian Jya(θ)	Modern R sine (θ)	θ	Indian Jya(θ)	Modern R sine (θ)
$3^0\ 34'$	225	224.856	$48^0\ 45'$	2585	2584.825
$7^0\ 30'$	449	448.749	$52^0 30'$	2728	2727.549
$11^0\ 15'$	671	627.720	$56^0\ 15'$	2859	2858.592
$15^0\ 0'$	890	889.820	$60^0\ 0'$	2978	2977.395
$18^0\ 45'$	1105	1105.109	$63^0\ 45'$	3084	3083.448
$22^0\ 30'$	1315	1315.666	$67^0\ 30'$	3177	3176.298
$26^0\ 15'$	1520	1520.589	$71^0\ 15'$	3256	3255.546
$30^0\ 0'$	1719	1719.000	$75^0\ 0'$	3321	3320.853
$33^0\ 45'$	1910	1910.050	$78^0\ 45'$	3372	3371.940
$37^0\ 30'$	2093	2092.922	$82^0\ 30'$	3409	3408.588
$41^0\ 15'$	2267	2266.831	$86^0\ 15'$	3431	3430.639
$45^0\ 0'$	2431	2431.033	$90^0\ 0'$	3438	3438.000

Though *Sūrya Siddhānta* uses a value of π as square root of 10, it gives a table indentical to that of Aryabhata with R = 3438. With the value of π in *Sūrya Siddhānta* R should have been 3415. This shows the heterogeneous character of *Sūrya Sidhānta.* Various astronomers used different values of R, though often Āryabhata's values have been quoted by the later authors. Vateśvara [19] uses more accurate value of R = 3437' 44". He has given Rsine table in the steps 56' 15".

The Indian astronomy reached Europe through Arabic astromomical texts during 11-13the century. Maslama al-Majriti (fl 1000 AD)edited al-Khwarizmi's astronomical tables (based on Indian astronomical works) which were translated into Latin by

Adelard of Bath (c 1142 AD) [20, Sen p.49]. In 1428 computations were made for the geographical latitude of Newminster, England using astronomical parameters and tables based on Lynn Thorndike's translation of anonymous fifteenth century Latin manuscript Asmole 191 II. The R sine tables were used with R taken as 150. It is to be noted Lalla (c 768 AD) gives a table of R sine with R = 150 in his work *Sisyādivrddhidātantra.* He gives R sine in the steps of 10^0 as 26, 51, 75, 96, 115, 130, 141, 148 and 150.

It should be mentioned that the Indian texts give several realtions among trigonometric functions. The interpolation formulae for using the tables have also been given. These are used in the present day numerical mathematics by the name of Newton.

The Indian astronomers were not using the decimal fractions and therefore used large integral numbers to obtain accuracy. Āryabhata identified the spherical triangles needed in the transformation of coordinates from one locality to another. The method of solving the indeterminate equations must havel played a dominant role in obtaining number of revolutions of various planets. Such methods were developed by Āryabhata I, Brahmagupta, Bhaskara I and II.

Of course in the work of Bhāskara II a very sound mathematician is revealed. He has dealt with problems involving differentials and integrals apart from highly evolved algebraic techniques. He preceds Western mathematicians by three or four centuries. It is however surprising after Bhāskara II, the mathematical astronomy in India did not progress much. Similar was the fate of Arabic astronomy which did not progress much after the 12th century.

4.1.5 Reference Zero Point of Time: The zero point of time, when the positions of planets are given, is a very important concept. For making an accurate forecast of astronomical phenomena, one needs to use long periods as well as a definition of zero point of time. All the planets were at the same longitude in the beginning of *Kaliyuga* according to Āryabhata. This seems to be an extrapolation backwards by him starting from his era. The prime meridion of India passed through Ujjayini and Laṅkā (located on the equator. Āryabhata defined this point as the first day of *Kaliyuga* starting at sunrise on Friday, 18th February 3120 BC at Lankā. The *Kali Samvat* in 1997 AD is 5098. The day count from the beginning of the Kali is called *Ahargana.* This is similar to the Julian date used in Western astronomy. Scaliger started his zero point of time - the Julian date, he took it as per the creation given in the Bible. The Julian date begins with January 1, 4713 BC. The Indian contribution, which preceded the developments of other civilisations, is not well recognised as is obvious from the following quotation taken from the Cambridge History of Science [21] -

"Mayans had devised a long term day count which was thought of as beginning some time in third millenium BC, and counted the days consevutively ever after. It is an excellent system for dating of past astronomical and historical events and it is much to Mayas' credit that they had the insight to think of it. A similar system, the so

called 'Julian day count' was deivsed in Western Europe by Joseph Scaliger in 1583 AD but this was not until six centuries after the Mayan."

4.1.6 Large Time Periods: The time periods used in the Indian astronomy are very large in magnitude. A *manuyuga* = 311 million yrs. This is comparable to a cosmic year (250 million yrs) which is the time taken by the Sun to revolve around the centre of the milky way. One day of *Brahmā* = twp *kalpas* = 8.7×10^9 yes is comparable to the age of universe in modern cosmology which is 15×10^9 years. The cosmological concepts of creation are also present in India as the age of Brahmā is given at the beginning of the Śaka era (77 AD) to be about 50 Brahmic years in Susi, SiSi, *Markandeya - purāna* and *Visnu-purāna* and about 8.5 Brahmic years in SiDVr, VSi and *Skanda-purāna.* The Indian time periods are much larger than even the ones used in modern science. At present some of the large time periods can be interpreted, however, it remains a puzzle how these time periods were arrived at. As mentioned earlier *Śatapatha Brāhmana* (c 2000-1000 BC) gives a *mahāyuga* similar to that of Āryabhata I.

4.1.7 Orbital Parameters and Planetary Models: Spherical earth is in use in Indian astronomy as is evident from the word *Bhūgola.* The longitudes and latitudes are used. The cardinal cities lying equally separated on equator are given. North pole and south pole are described to be inhabited by Gods and demons respectively. They are described to have day and night each of six months duration in opposite phase.

The *Siddhāntic* texts give the number of revolutions in a *Yuga* for various planets. The revolution number is equivalent to frequency and the difference of revolution numbers of two planets has clear-cut significance in obtaining their relative frequency. For example the sidereal period in days of the rotation of a planet can be derived as

$$\text{Period}_{\text{planet}} = \frac{R_{\text{earth}} - R_{\text{Sun}}}{R_{\text{planet}}}, \tag{1}$$

where $R_{\text{earth}}, R_{\text{Sun}}$ and R_{planet} are respectively the revolution numbers in a *yuga* of the Earth, Sun and the planet. The synodic period in days is given as

$$\text{Period}_{\text{synodic, planet}} = \frac{R_{\text{earth}} - R_{\text{Sun}}}{\mid R_{\text{planet}} - R_{\text{Sun}} \mid}. \tag{2}$$

Āryabhata gives R_{earth} where earth is rotating around its own axis. For geostationary system the asterisms are rotating around the earth and there R_{asterism} is used in place of R_{earth}. As the rotation is relative, either of the two is an admissible concept in the astronomical computations.

The revolution numbers given by Āryabhata I and Sāmanta Chandra Sekhar are given in Table 4. The period deduced from these are compared with the modern values.

It is pointed out by Somayāji [20] that for a planet the sidereal period was obtained from the synodic period by taking into account the period of the Sun as mentioned above. The synodic periods lie between about a month to about three years, they are easy to record and can be used to calculate the sidereal period. The calculation of a planetary position is carried out in three steps. In the first step the mean position is obtained by taking a circular orbit and by multiplying the revolution frequency by the elapsed time since the zero time. The correct geocentric longitude is further obtained from the mean position by applying two corrections, namely the *manda samskara* and the *śighra samskra*. The application of *manda samskara* is equivalent to take into account the eccentricity of the orbit. The *manda samskara* agrees [3] to the first order with the equation of centre in modern astronomy. Then the application of *śighra samskara* is equivalent to converting the heliocentric longitude into the geocentric longitude as discussed by Somayaji and Ramasubramanian et al. [22]. The latter authors discuss the contribution of Parameśvara (AD 1380-1460) and Nīlakantha Somayājī (AD 1444 - 1550). Nīlakantha had discussed the geometrical model implied in the earlier Indian astronomy. He unified the different *śighra samskaras* applied to the interior and the exterior planets. He then described the planetary model thus:

"The (eccentric) orbits on which planets themselves move (*graha-bhraman vrtta*) at the same rate as the apldes (*uccha-gati*) on *manda-vrtta* [or the manda epicycle drawn with its centre coinciding with the centre of the *manda* cocentric]. In the case of Sun and the Moon, the centre of the Earth is the centre of this *manda-vrtta*. For the others [namely the planets Mercury, Venus, Jupiter and Saturn] the centre of *manda-vrtta* moves at the same rate as the mean Sun (*madhyārkagati*) on the *śighra-vrtta* [or the *śighra* epicycle drawn with its centre coinciding with the centre of the sighra cocentric]. The *śighra-vrtta* of these planets is not inclined with respect to the ecliptic and has the centre of the celestial sphere as its centre. In the case of Mercury and Venus, the dimension of the *śighra-vrtta* is taken to be that of the cocentric and the dimensions [of the epicycles] mentioned are their own orbits. Further, here the *manda-vrtta* [and hence manda epicycle of all planets] undergoes increase and decrease in size in the same way as the *karna* [or the hypotenuse] or the distance of the planet from the *manda* cocentric."

In the Nilakantha's planetary model Mercury, Venus, Mars, Jupiter and Saturn, are assumed to move in cocentric orbits around the *Śighroccā*, which is the mean Sun going around the Earth. The planetary orbits are tilted with respect to the orbit of the Sun or the ecliptic and hence cause the motion in latitude. This work preceded Kepler's model b more than a hundred years.

There is a widespread belief about the geocentric universe as the planetary model in the India as well as the Greek astronomy. It is believed that Copernican revolution followed by Tycho Brahe's accurate measurements, paved the way for the Kepler's planetary heliocentric model, finally culminating in Newton's formulation in terms of the gravitational interaction. Of course in Europe the belief about the flatness of Earth, the geostationary and geocentric universe prevailed and talking against these concepts led to the persecution of Galileo. Situation in India was very different.

Āryabhata I talked about the rotation of the earth in place of the heavens moving about the earth. This merely let to a criticism by other astronomers, and the Kerala school even followed Āryabhata's postulates. The astronomical observations are made with respect to earth and all its motions are to be properly corrected for obtaining the data needed for the heliocentric model.

4.2 Contributions of Samanta Chandra Sekhar

One of the most recent *Siddhāntic* Indian astronomer is Samanta Chandra Sekhar [AD 1835 - 1904] [11] born in Khandapara, Orissa. He made several observations using simple instruments and finally wrote his treatise *Siddhānta Darpana* in 1869 on palm leaves in Sanskrit in Oriya script. It was published on paper in 1899 in Devanagari script with an English summary by J. C. Ray. The astronomical journal 'Knowledge' in 1899 described him as the best naked eye astronomer known so far. His observations match well with the modern measurements.

The orbital parameters of Samanta Chandra Sekhar along with that of Aryabata I and the modern ones are given in the Table 4. The accuracy of Chandra Sekhar's observations is obvious. The Indian astronomers described the lunar and solar eclipses, though some times the discrepancies were observed. The so called *Rahu* is the motion of the ascending node of moon's orbit and is not any *rakshasa* as pointed out e.g. by Lalla. The motion of moon is very complex on which Manjula (AD 932) and Bhaskara II (AD 1150) also worked. Manjula described the term causing evection while Bhaskara described the term called variation. Chandra Sekhar also considered the term due to annual variation. All the terms result in more accurate prediction of eclipses.

Precession of equinoxes which causes i.e. the shifting of the pole star with time has been described by Manjula. He gave a value $59.2''$ per year while Chandra Sekhar gives a value $57.615''$. After correcting for the reference system, it becomes $47.179''$ agreeing with the modern value $50.3''$. More work is required to understand Chandra Sekhar's contribution.

5 Impact of Zij Astronomy on the Indian Tradition

Jaisimha's astronomer Jagannath Samrat (fl. 1720 AD) translated Ptolemy's (2nd century AD) *Almajest* in Sanskrit under the name *Samrat Siddhānta.* This text probably also contains original material written by him as well. Jai Simha's (18th century) recordings have been meticulously documented in Zzij Muhammad-sahhi. Maulala Ghulam Husain of Jaunpur wrote an astronomical text Jami Bahadur Khani in 1834 [20]. There is a lot of Zij literature from the Muslim period in India.

6 Impact of Siddhānta on the astronomy in Europe and other Countries

Regis Blachere translated in 1935 Said-al-Andalusi's text prepared in 11th century recording old Arabic traditions about Indian astronomy [20]. Said stated that only eight nations were interested in and comprehended science. These people were the Hindus , the Persians, the Chaldeans, the Jews, the Greeks, the Romans, the Egptians and the Arabs. In the nations who cultivated sciences, he placed Hindus at the head. Varāhamihira's (fl. 505 AD) *Panchsiddhāntikā* was translated into Chinese by Ch'u-Ta'n-Hsita (718 AD) as Chiu-chih-li [20]. The Chinese astronomy was strongly influenced by the Indian astronomy thereafter. Already the effect on Arabic astronomy and the British astronomy has been mentioned.

7 Concluding Remarks

Though presently we train ourselves in sciences in Western tradition, I conclude by saying that a proper understanding of the Indian Astronomical texts will boost our confidence eliminating the false concept about the lack of roots of science in the Indian society. At times it can provide us new ideas in the field of scientific research.

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Planetary Motion as in Siddhānta Darpana

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1 Introduction

Siddhānta Darpan by Samanta Chandra Sekhar (1835 - 1904) is a systematic treatise on traditional Indian astronomy . A short account of the life and work of this author (SCS) has recently been published[1] in which the characteristic features of a *Siddhānta*, as traditionally described, has been enumerated. All such astronomical works including the '*tantras*' and the '*karanas*' deal with details of planetary motions with prime importance. *Siddhānta Darpana* deals with this matter quite extensively.

Table 1.

Planet	*Surya Siddhānta*	*Siddhānta Siromani*	*Siddhānta Darpana*	European Values as in 1899	Modern values
Sun	365.2585	365.25843	365.25875	365.25637	365.25636
Moon	27.32167	27.32114	27.32167	27.32166	27.3216615
Mars	686.9975	686.9979	686.9875	686.9794	686.97982
Mercury	87.9585	87.9699	87.9701	87.9692	87.969256
Jupiter	4332.3206	4332.2408	4332.6278	4332.5848	4332.589
Venus	224.6985	224.9679	224.7023	224.7007	224.70080
Saturn	10765.7730	10765.8152	10759.7605	10759.2197	10759.23

All traditional works hold sun, moon and the five *taragrahas* (Mercury, Venus, Mars, Jupiter and Saturn) as '*graha*' and let us call them the generalised planets. In addition to their diurnal motion in the westernly direction, they do go shifting slowly towards the east in the back ground of the stars, completing revolutions in definite periods. Such periods are important astronomical elements and so they have been determined with utmost accuracy through the ages. We cite in the following, the periods of sidereal revolutions of the planets, their *manda*, *sighra* and *pata* as given by various *Siddhāntas* and the modern astronomy (Table-1). One may check the close agreement of the *Siddhānta Darpana* with the modern value. More striking is the daily average rate of motion of planets given in this work, meticulously given upto ten places in sexagesimal system (Table-2). This needs be cited in order to ascertain

the care that the author (SCS) has taken to attain the possible degree of accuracy in dealing with the planetary motion.

Table 2.

Planet	Modern value (Lahiri)	Brahmagupta Sripati Bhāskara	Samanta Chandra Sekhar
Sun	0 59 08.2	0 59/8/10/21 0 59 8.1725	59/8/10/10/24/12/30/4/10/4
Moon	13 10 35.0	13/10/34/53/0 13 10 34.8833	790/34/52/3/49/8/2/16/10/11
Mars	0 31 26.5	0/31/26/28/7 0 31 26.4686	31/26/30/6/47/44/32/49/3/4
Mercury	4 05 32.4	4/05/32/18/28 4 5 32.3077	245/32/16/7/17/17/59/43/42/44
Jupiter	0 40 59.1	0/04/59/9/9 0 04 59.1525	4/59/5/37/0/36/41/17/1/51
Venus	1 36 07.7	1/36/7/44/35 1 36 7.74305	96/7/37/47/57/50/39/32/31/35
Saturn	0 02 01.9	0/2/0/22/51 0 2 0.380833	2/0/26/55/2/53/21/2/4/54
Moon's nodes	-0 03 10.6	0/03/10/48/20 0 30 10.8055	3/10/47/40/40/26/11/25/13/30

Of course, such periods of revolutions and rates are not traditionally arrived at by direct observations. Infact they are obtained by certain surmise. Each traditional author assumes a definite number of ' *bhaganas*' (revolutions) of the planets during certain time interval (epoch). One arrives at the period and rate out of such assumptions. Of course, these figures are designed to tally with observed motion of the planets. This is about their mean motion.

Description of events like solar and lunar eclipses, transits, occultations, alignments are of paramount importance in all astronomical works. Predictions of such events and their agreement with observations are the acid tests of such works. Such calculations involve detailed study of various kinds of planetary motion,the cause of such motions and prescription of corrections due to various distracting or influencing

agencies on the planets. Infact, most of the *Siddhāntas* elaborately deal with such matters in sections called the *sphutadhikara* (on the true motion) of the planets.

It is natural in this context to judge the view of the concerned author regarding the prime source of attraction for the planets: either Earth or the Sun. It is also a matter of curiosity to notice the nature of paths of planets as indicated in such works. We will briefly touch upon these aspects of the study of planetary motion as given by SCS. We will notice that the author supports the usual epicycle hypothesis, adds an extra epicycle of *parocia*, in addition to the *mandocea* and *Sighrocia* in case of Mercury, Mars and Saturn. Most striking is Samanta's helio-cum-geocentric concept of the solar system, quite akin to that of Tycho - Brahe. We outline in the following sections such aspects of planetary motion, according to the *Siddhānta Darpana.*

2 Various types of motion

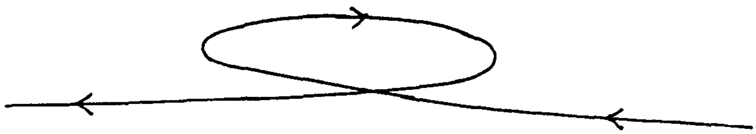


Fig. 1.

The nature of motion of Sun and Moon are always forward i.e. easternly in the star back-ground. However, the motion of the *taragrahas* are sometimes retrograde causing them to appear to move in a loop (Fig-1).

One finds description of eight types of motion of planets as described in *Siddhāntas*, particularly in *Surya Siddhānta*[2] (Chapter-II,Versc- 12,13). They are (S.D. *Sloka*-12).

vakra (retrograde)
anuvakra (some what retrograde)
vikala (transverse)
manda (slow)
mandatara (very slow)
sama (even)
Sighra (swift)
Sighratara (very swift)

Samanta Chandra Sekhar in *Siddhānta Darpana* quotes these motions from the *Surya Siddhānta* and then explains them[3] (S.D. Ch.V, *Slokas*.37-40).

Of these, *vakra* and *anuvakra* are backward motions, *vikala* is the apparent null motion ; *Manda* and *sighra* motions refer to speeds slower or swifter compared to the mean motion of the planet. Speed equal with the mean is called the *sama* (even).

3 The Epicycle Hypothesis

Such motion of the planets has been given explanation in light of epicycles. Such hypothesis is seen to have been advocated by the Greek (starting with Ptelomy) and Hindu astronomers[4] (starting with Aryabhata), of course with differing features in details. We out-line in the following the basic concept of epicycle motion.The model suggests that each planet including the sun and the moon, moves in a circle called the epicycle, the centre of which in turn moves in another circle, centered at the Earth (Fig-2). The latter circle is called the deferent. The motion along the deferent is always anti-clock-wise, where as that along the epicycle circle may be either clock-wise or anti-clock-wise. The angular speeds ω_1 and ω_2 may be different as well. The radii of the deferent and epicycle circle may be taken constant or that of the latter circle variable.

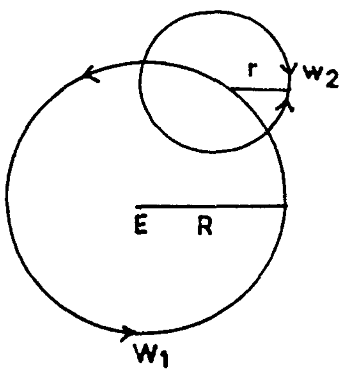


Fig. 2.

Now depending upon the relative positions and speeds, the motion of planets may be visualised from the picture to be forward, backward and even at times null. One may notice the rough picture of the observed planetary orbit from locus of successive position of a point on an epicycle circles depicted in Fig-3. In order to reach an agreement with the observed motion of planets, one may go on adding various finer epicycles.

It needs be pointed out here that the epicycle model is purely kinematic and the dynamical origin of such motion for argument sake even is rather complicated. For example, the simplest of epicycle motion corresponds to oscillatory motion of

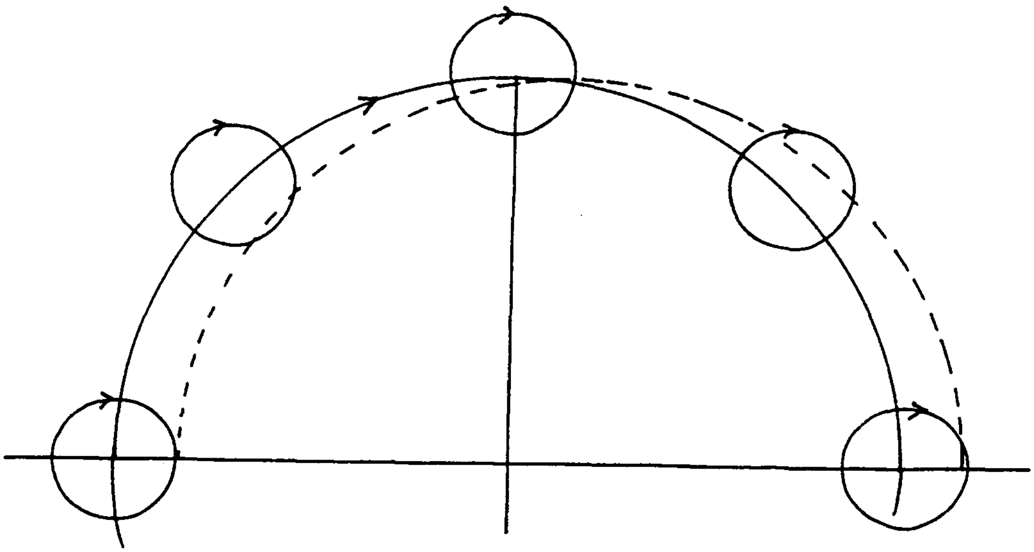


Fig. 3.

a charged particle inside a magnetron[5]. Therefore, in the later times, Ptolemy's epicycle model was not considered as a viable physical model of the planetary motion. There came reforms in the hands of Copernicus, Kepler and Newton.

4 Fictitious Forces

Traditional Indian Astronomy relies on hypothesis of existence of fictitious forces which produce irregularities in the apparent motion of the planets taken to be real in their frame. Of course, such forces are not dealt with from the point of dynamics and are dealt rather geometrically. Burgess in *Surya Siddhānta*[6] observes, " The Hindu Method × × absolves from all necessity of adopting the disturbing forces × × and making them form a constant system, capable of geometrical representation and mathematical demonstration ". Such disturbing forces have been clearly spelt out in most of the earlier works, including *Surya Siddhānta* and *Siddhānta Siromani*. We cite in the following such descriptions from*Surya Siddhānta*, Chapter- II, *Slokas* 1-5.

Forms of time of invisible shape stationed on the Zodiac(*bhagana*) called the conjuction(*sighrocca*) and apsis(*mandocca*) and nodes(*pata*) are the cause of motion of planets.

The planets attached to these beings by the chord of air, are drawn away by them with the right and left hand, forward or backward according to the nearness towards their own place.

A wind, moreover, called the provector(*prabaha*) impels them towards their own apcices(*ucca*) ; being drawn away forward and backward, they proceed by a varying motion.

The so-called apex(*ucca*), when in their half-orbit in front of the planet, draws the planet forward; in like manner, when in the half-orbit behind the planet, it draws it back-word.

When the planets drawn away by their apcices(*ucca*) move forward in their orbits, the amount of motion so caused is called their excess(*dhana*); when they are backward, it is called their deficiency(*runa*).

5 The Manda and Sighra Geometry

SCS says, the attraction of *mandocca* causes first five kinds of motions namely *manda, mandatara, sama, sighra* and *sighratara*. And *sighrocca* causes the latter three kinds i.e. *vakra, anuvakra* and*vikala*(S.D. Ch-V, *Sloka*- 41). The author also clearly says that, the Sun and Moon have *mandocca* only and no *sighrocca*; and for that only they do not under go retrograde motion.

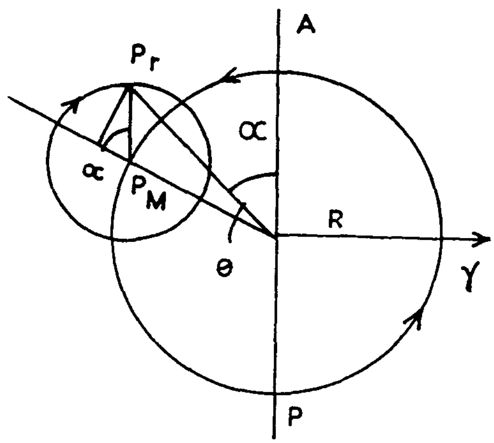


Fig. 4.

Geometry of the planetary motion for the *manda* correction is depicted in Fig-4[7, 8]. The mean planet moves on the deferent in anti-clock-wise direction. The true planet moves on the epicycle circle with the same angular speed as the mean planet ,but in the clock-wise direction. If R be the radius of the deferent, r that of the epicycle circle, α, the anomaly, i.e. the difference of the angular positions of the mean planet and the true planet,

$$R \sin\theta = \frac{r \sin\alpha}{\sqrt{(R + r\cos\alpha)^2 + (r\sin\alpha)^2}} \tag{1}$$

If $r << R$, then $\sin\theta = \frac{r}{R} \times \sin\alpha$

$$\text{i. e. } \theta \cong \frac{r}{R} \sin\alpha \tag{2}$$

Here θ is the *mandaphala.*

In case of the *taragrahas,* the *sighra* correction is to be further applied. Its physical effect is to correlate the observed motion in which the planets do move in heliocentric way for the geocentric observer. The geometry of *sighra* correction for the inner and outer planets are different and they are given in figs.5&6. For an outer planet, $\alpha_s$is the mean longitude of the sun, $\alpha_p$the longitude of the *manda* corrected planet. $(\alpha_s - \alpha_p)$ is called the *sighra kendra.* But α_t is the true longitude of the planet on the *sighra* epicycle. Naturally (α_t- α_p) is called the *sighra phala* or the *sighra* correction. The *sighra phala* is given by

$$\tan(\alpha_t - \alpha_p) = \frac{r\sin(\alpha_s - \alpha_p)}{R + r\cos(\alpha_s - \alpha_p)} \tag{3}$$

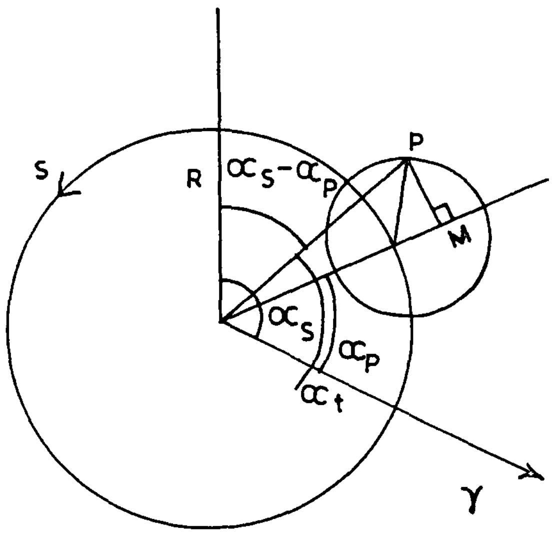


Fig. 5.

For an interior planet, the *sighrocca* is at M and the mean sun, which is the mean planet at S. The true planet is at P. Now $(\alpha_p - \alpha_s)$ is the *sighra kendra* and $(\alpha_t - \alpha_s)$ is the *sighra phala* given by

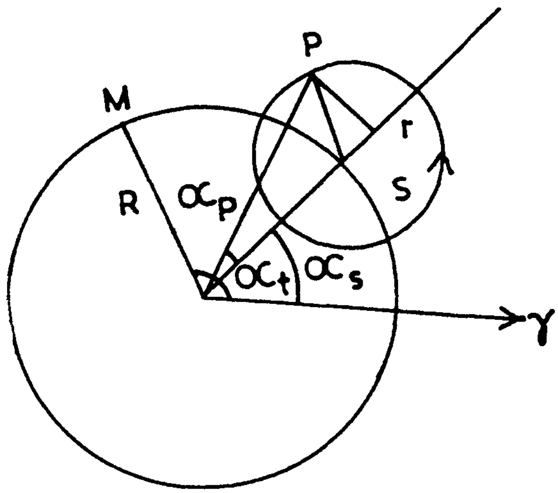


Fig. 6.

$$\tan(\alpha_t - \alpha_s) = \frac{r\sin(\alpha_p - \alpha_s)}{R + r\cos(\alpha_p - \alpha_s)} \qquad (4)$$

The details of *mandocca* and *sighrocca* corrections are elaborately discussed in *Siddhānta Darpana* and a number of tables there of given in the *sarinis*(table).

6 The Parocca Correction

Samanta Chandra Sekhar prescribes a further correction, called the parocca to be applied to Mars, Mercury and Saturn. In *sloka* 76-78 Ch..V, SCS says, I have noticed the *mandocca* of Mars, Mercury and Saturn and the *sighrocca* of mercury to be moving both forward and back ward. Therefore, I have imagined another being, called *parocca*, to be effecting such motion. The positions of the *parocca* are as follows.

1. The *parocca* of Mars′ apsices is located 180^0 ahead of the mean sun.
2. The *sighrocca* of Mercury is the *parocca* of its apsis and vice versa i.e. the *parocca* of the *sighrocca* of Mercury is its apsis.
3. The *parocca* of *mandocca* of Saturn is 180^0 behind the mean Saturn.
   [hbt]
   Now the geometry of the *parocca* correction according to the above prescriptions can be visualised as in the following set of diagrams in Fig-7. For Mars, S is the mean sun and M, the mean planet (*mandocca* and *sighrocca* corrected). So M′ is

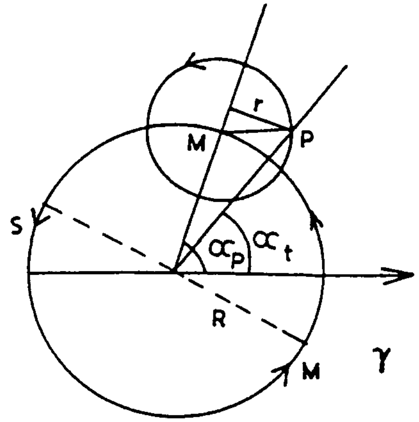


Fig. 7.

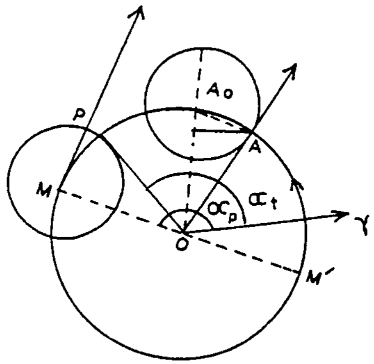


Fig. 8.

the position of the parocca and P is the true planet. Naturally, $(\alpha_p - \alpha_t)$ is the *paraphala* in longitude, which will be given by

$$\tan(\alpha_p - \alpha_t) = \frac{r \sin \alpha_p}{R + r \cos \alpha_p} \tag{5}$$

For the Saturn, if A_0 is the *mandocca* and M, the mean planet, M′ is the *parocca* of the *mandocca* and as a result the true *mandocca* is at A′. Consequently, MP||O A′ gives the position of the true plane at P. Similarly, the geometry for Mercury can be constructed and the trigonometric formulae for the *parocca* corrections for each case be established. Of course, SCS has given in the text, the results of such calculations and elaborations of such results will be presented else where. It has to be noted that such finer corrections by SCS are introduced inorder to bring agreement of predictions with observation.

7 Planetary Orbits

In order to explain the observed motion of the planets, *Bhaskaracharya* brought in the eccentric circle hypothesis in which, the centre of a planet does not coincide with the centre of the Earth. Hence an observer on the surface of the Earth finds the true planet's position differing from that of the mean planet, so that what is called the *Bhujaphala correction* is to be made in the mean position of the planet to get the true position." This is achieved by imagining an eccentric circle, on which the planet moves (Fig-8).

Let E be the centre of the celestial sphere i.e. the centre of the Earth and E′ the centre of the eccentric circle. M be the position of the mean planet. Then P, vertically above M is the position of the true planet on the eccentric circle. This particularly applies to the Sun and Moon and to the *taragrahas* with proper rectifications.

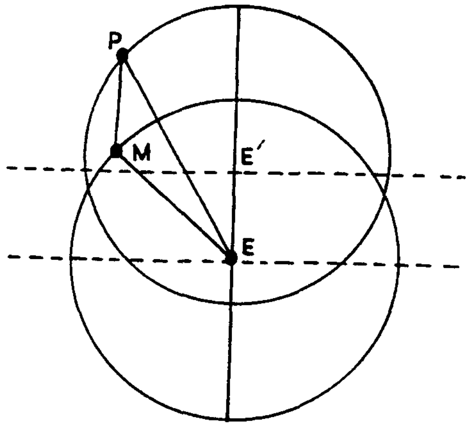


Fig. 9.

SCS while quoting the arguments of *Bhaskaracharya*, goes still further(S.D. Ch.21,Sloka 92-94) to say, "In order to see the true motion of the planets, assume one digit equal to 60 *kalas* and take 115/2 digit long thread to make an isosceles triangle of base of 10 digits lying between the centre of the Earth and the *mandocca*, connecting them. Now rotate the sides of the isosceles thread to get a *prativrtta*."

This clearly is an ellipse. But SCS does not say that the planets do move in ellipses and the ellipse described here are not exactly the actual elliptic orbits of the planets. But he uses this ellipse to give the rectification to the motion of the planets. In this respect, SCS is more akin to Kepler's orbits.
Noteworthy in this connection is the solar system model given in the *Siddhānta Darpana*. In Chapter-5,sloka 6-7, SCS says: "The mean sun moves around the

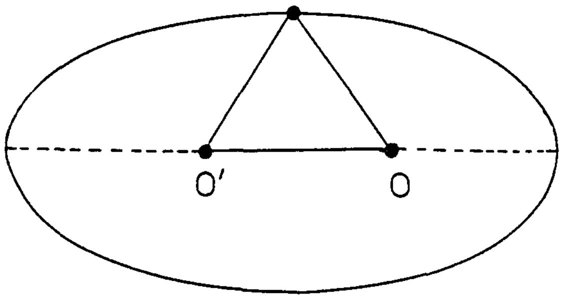


Fig. 10.

Earth. It lies at the centre of the orbits of the planets and asterisms. The five visible planets (*taragrahas*) move around the Earth with the sun." Therefore it is clear that the mean sun is taken to be the centre of attraction of all celestial objects. Such descriptions are found in other places in the text also and particularly in Chapter-16. It is quoted by the critics that such model of the solar system led to exact agreement of the calculation with observation and Kapileswara Sastri in his commentary to *Suriya Siddhānta* has complemented[10] SCS in glowing terms. Such model of the solar system tallies exactly with that of Tycho Brahe.

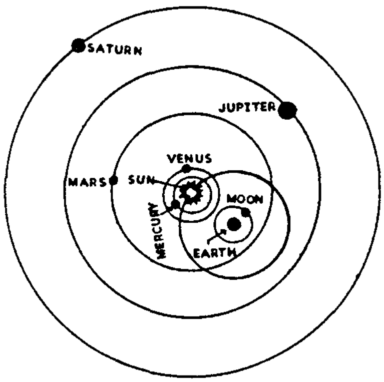


Fig. 11.

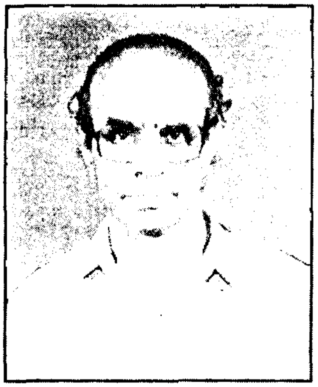
It is worth pointing out here that recently Ramasubramanian et. al. have shown that Nilakantha Somasatva[11] in Kerala in 15^{th} century advocated formulations which implied such a model. But the accounts of SCS are explicit and clearcut.

8 Concluding Remarks

In this article I have mentioned a few aspects, in way of presenting bare ideas only in respect of planetary motion as in *Siddhānta Darpan.* It may be noticed that a number of features due to SCS are original.

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Corrections for Planets' Positions and Samanta Chandra Sekhar

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1 Introduction

In the Indian astronomical tradition, the practice of introducing *bījas* (corrections) to the parameters has been in vogue for long. The Indian astronomers were aware that the values of the governing parameters, given by them, would be valid only for a century or so and that future competent astronomers should provide further improvements.

For example, the celebrated Kerala astronomer, Parameśvara states:

Kālāntare tu samskāraścintyatām ganakottamaiah —

"In the course of time, the (necessary) corrections must be decided by the expert mathematicians". In fact, Parameśvara in his extensive work on computations of eclipses - *Grahanamandana-* observes in all humility that the times of contact etc. of an eclipse as given by him *may at times* differ *slightly* from observed positions *(Kālo anena ca siddhah kadācidapi bhidyate svalpam).*

In the famous *karana* text, *Laghumānasam,* Mañjula, (or Muñjala) composed five *ślokas* separately in the *āryā* metre while the main text of 60 *ślokas* was in *anustubh* metre. In the *āryā* verses Mañjula has given the planetary details for his epoch. Giving reasons for the separate treatment of the five verses, the commentator Sūryadeva Yajvă suggests:

> The epochal positions stated in those (five) verses will not serve for more than 100 years and after every century thereafter these will have to be replaced by new verses giving new epochal positions.

Again, the famous astronomer Jyesthadeva (c. 16th century) in his Malayalam text *Drkkarana* described the long series of revisions introduced over centuries in the Āryabhatan system of astronomy. He says:

1. In the Kali year *"girituṅga"* (i.e. 3623 ≡ 522 A.D.), his work *(Āryabhatīyam)* was composed .... He had adjusted the (planets') revolutions by reduction and addition in such a way that there was no zero correction at the beginning of Kali.

2. In course of time, deviations were observed in (the results arrived at by) this computation. Then, in the Kali year *mandasthala* (3785 ≡ 684 A.D.), several astronomers gathered together and devised, through observation, a system wherein (the correct mean longitudes were to be found) by multiplying the current Kali year minus *"giritunga"* (Kali 3623 i.e. the epoch). This system was named *Parahita* and many followed it, assuring themselves of its accuracy.
3. When a long time had elapsed, there occurred substantial deviations. Then a noble *brāhmana*, Parameśvara residing on the coast of the Western Ocean revised the *Parahita* system by means of astronomical observations in the Kali year *"raṅgaśobhānu"* (4532 ≡ 1431 A.D.).
4. the work *Tantrasaṅgraha* by Nīlakantha (Somayāji), with revised constants, is for twelve years later.
5. The revolutions given therein (i.e. in the *Tantrasaṅgraha*) too, becoming imperfect (in course of time), observations were continued by the astronomers on the West Coast for 30 years, from the Kali year *"jaustava"* (4678 ≡ 1577 A.D.) through the *Kali* year *"jhanasevānu"* (4709 ≡ 1607 A.D.) and, by observation, the astronomical tradition was revised accurately.

Henceforth too, deviations between calculated and observed positions of planets should be carefully observed and revisions effected.

Again, there is a detailed statement in the *Brhat-tithi-cintāmani*, by Ganeśa Daivajña (16th century A.D.) describing how *śāstra* which is *tathya* (accurate) at one period of time becomes *ślatha* (inaccurate) and needs *samsthāpana* in any later period.

The celebrated astronomer Nīlakantha Somayāji, referring to a certain commentator of Mañjula's *"Mānasam"* who laments, "Alas ! we have precipitated into a calamity - *mahati saṅkate patitāh smah"* points out:

"....... One has to realize that the five *siddhāntas* had been correct at a particular period. Therefore, one should search for a(new) *siddhānta* that does not show discord with actual observation (at the present time). Such accordance with observation has to be ascertained by (astronomical) observers during times of eclipses etc."

2 *Bijas* for civil days and revolutions, *mandoccas*, epicycles etc. of planets

In Indian astronomy, computations of true positions of planets are based mainly on the following parameters:

1. Number of civil days in a *Mahāyuga* (or *Kalpa*)
2. Mean rate of daily motion given in terms of the number of revolutions in a *Mahāyuga* (or *Kalpa*);
3. The rates of motion of the *mandoccas* (apogees) of the planets in terms of revolutions in a *Mahāyuga* (or *Kalpa*);
4. The peripheries of the *manda* and *śīghra* epicycles of planets; and

5. The epochal positions of bodies and special points.

In the present chapter we propose suitable *bījas* (corrections) to the above parameters based on modern scientific computations. The parameters related to the items mentioned above are now considered one by one.

2.1 Civil days in *Mahāyuga*

In a *Mahāyuga*, the sun completes 432×10^4 revolutions; the period of one revolution with reference to fixed stars being defined as a sidereal solar year.

Taking the modern value of the *sidereal* sun's daily motion as SDM= 3548". 1928098 the duration of a sidereal solar year becomes 365.2563627378105. However, allowing a maximum error of ± 5 in the eighth digit in the value of SDM, correspondingly, the duration of a sidereal solar year lies between 365.2563627429576 days and 365.2563627326635 days.

Accordingly, the number of *civil days* in a *Mahāyuga* of 432×10^4 years turns out to be 1577907487 days (ignoring the decimal part). However, if the longer period of a *Kalpa* of 432×10^7 years is considered, we can have a more accurate figure for the number of civil days as 1577907487027 in a *Kalpa*.

Now, the numbers of civil days in a *Mahāyuga* according to some of important traditional texts and the proposed value are compared in Table 1. Proposed *bīja* of

Table 1. Civil days in a *Mahāyuga*

Texts	No. of civil days
1. Āryabhata I *(Āryabhatiyam)*	1,57,79,17,500
2. Brahamagupta's *Khandakhādyaka*	1,57,79,17,800
3. *Sūrya siddhānta (SS)*	1,57,79,17,828
4. Āryabhata II (*Mahāsiddhānta*)	1,57,79,17,542
5. Bhāskara II (*Siddhānta śiromani*)	1,57,79,16,450
6. Proposed modern value	1,57,79,07,487

SS value is - 10,341. It may be noted that Bhāskara II (1114 A.D.) suggested a *bīja* of - 1,378 to the SS value. Chandra Sekhar Simha adopts the SS value.

2.2 Revolutions of bodies in a *Mahāyuga*

The mean motion of a heavenly body is determined from its number of revolutions in a *Mahāyuga* of 432×10^4 years.

In our proposed values for the revolutions of the sun, the moon and other bodies, we have considered the rate of daily change in the sidereal longitude of these bodies. In Table 2, the numbers of revolutions of the bodies according to the traditional texts are compared with the suggested modern values.

Table 2. Revolutions of bodies in a *Mahāyuga*

	Bodies	Āryabhata I Brahmagupta	*Sūrya siddhānta*	Bhāskara II	Chandra Sekhara Simha	Proposed Modern
1.	Ravi	43,20,000	43,20,000	43,20,000	43,20,000	43,20,000
2.	Candra	5,77,53,336	5,77,53,336	5,77,53,300	5,77,53,336	5,77,52,986
3.	Candra's *Mandocca*	4,88,219	4,88,203	4,88,206	4,88,118	4,88,125
4.	Rāhu	2,32,226	2,32,238	2,32,311	2,32,298	2,32,269
5.	Kuja	22,96,824	22,96,832	22,96,828	22,96,871	22,96,876
6.	Budha's *śīghrocca*	1,79,37,020	1,79,37,060	1,79,36,999	1,79,36,967	1,79,37,034
7.	Guru	3,64,224	3,64,220	3,64,226	3,64,155	3,64,195
8.	Śukra's *śīghrocca*	70,22,388	70,22,376	70,22,389	70,22,258	70,22,260
9.	Śani	1,46,564	1,46,568	1,46,567	1,46,650	1,46,656

Note: The traditional *siddhāntas* have given the revolutions of the bodies in a *Kalpa* of 432×10^7 years. However, in Table 2, we have reduced them for a *Mahāyuga* of 432×10^4 years (by dividing the figures by 1000) rounding off to the nearest integer.

2.3 Peripheries of *manda* epicycles

The expression for the *manda* equation is given by

$$E = \frac{a}{R} \sin m \tag{1}$$

where a is the periphery in degrees of the *manda* epicycle, $R = 360^0$ and m is the *manda* anomaly of the body.

The corresponding modern formula for the equation of centre, considering the first two terms is

$$E = (2e - \frac{1}{4}e^3) \sin m + \left[\frac{5}{4}e^2 - \frac{11}{24}e^4\right] \sin 2m \tag{2}$$

where e is the eccentricity of the body's elliptical orbit. Generally, since e is small, ignoring the higher powers of e, the equation of centre is approximated as

$$E \simeq (2e) \sin m \tag{3}$$

However, in proposing *bīja* to the peripheries of the *manda* epicycles of the heavenly bodies, we now consider even the higher powers of e viz. e^2, e^3 and e^4.

Let $e_1 = 2e - \frac{1}{4}e^3$ and $e_2 = \frac{5}{4}e^2 - \frac{11}{24}e^4$.

Thus (2) can be written as

$$\begin{aligned} E &= e_1 \sin m + e_2 \sin 2m \quad (4) \\ &= e_1 \sin m + 2e_2 \sin mosm \\ \text{or } E &= (e_1 + 2e_2osm) \sin m \end{aligned}$$

Here, it is interesting to note that the co-efficient of $\sin m$ is a variable and that most of the traditional texts indeed have taken the coefficient of $\sin m$ viz. a/R as a variable.

In Table 3, the proposed peripheries (in degree) for the different celestial bodies based on (4) above, are given using the current values of the eccentricities of the orbits of the bodies.

Table 3. Peripheries of *manda* epicycles

Planet	Periphery (Deg)		Coefft. of Equation of Centre					
	Min	Max	Min			Max		
			D	M	S	D	M	S
Ravi	11.80781	12.31284	1	52	45	1	57	34
Candra	36.8085	42.22932	5	51	29	6	43	15
Budha	109.8002	184.7195	17	28	30	29	23	56
Śukra	4.869	4.952738	0	46	29	0	47	17
Kuja	59.30061	74.92371	9	26	16	11	55	28
Guru	32.69004	36.89168	5	12	10	5	52	17
Śani	37.41842	43.03509	5	57	19	6	50	57
Uranus	31.42751	35.29051	5	0	6	5	36	59
Neptune	6.404953	6.550653	1	1	9	1	2	33
Pluto	123.0071	230.9876	19	34	37	36	45	46

The second and third columns give respectively the minimum and maximum values of the peripheries (in degrees) of the *manda* epicycles.

Correspondingly, the fourth and the fifth columns provide respectively the minimum and the maximum values of the coefficients (in deg., min and sec.) of sin m of the *manda* equation (1). We have included Uranus, Neptune and Pluto also in the list of planets.

The eccentricity $\underset{\sim}{e}$ of the earth's orbit is given by

$$\underset{\sim}{e} = 0.01675104 - (0.0000418)T - (1.26 \times 10^{-7})T^2$$

where T is the number of Julian centuries (of 36525 days each) completed since the epoch 1900.0 A.D. Accordingly, over centuries, the eccentricity $\underset{\sim}{e}$ and hence the periphery of the *manda* epicycle change. The coefficients of the equations of centre given by **Samanta Chandra Sekhar** are close to our suggested values.

2.4 Peripheries of *Śīghra* epicycles of planets

The peripheries of the *śīghra* epicycles of the different planets taken by the various *Siddhāntic* texts are presented in Table 4.

In fact, it is found that the periphery of the *śighra* epicycle of a planet is related to its mean heliocentric distance a. For the inferior planets viz., Budha and Śukra, the periphery of the *śīghra* epicycle is given by $p = (360^0 a)$ where a is in astronomical units. One astronomical unit (a.u.) is defined as the mean distance of the earth from the sun.

In Table 4 the peripheries of the *śīghra* epicycles of the planets according to the traditional texts are compared with the modern values (considering the mean heliocentric distances of the planets). In the case of the superior planets viz., Kuja, Guru, Śani and the trans-saturnine planets, the periphery is given by $p = (360^0/a)$.

Table 4. Peripheries of ***śīghra*** epicycles

Planets	Mean heliocentric distance a	*Āryabhatīyam*	*Khanda Khādyaka*	*Sūryasiddhānta*	Modern
Budha	0.3870986	130.5 - 139.5	132	132 - 133	139.3555
Śukra	0.7233316	256.5 - 265.5	260	260 - 262	260.3994
Kuja	1.523692	229.5 - 239.5	234	232 - 235	236.2682
Guru	5.202561	67.5 - 72	72	70 - 72	69.1967
Śani	9.554747	36.5 - 40	40	39 - 40	37.6776

Note: The peripheries are in degrees.

According to modern astronomy, the mean heliocentric distance a i.e. the *semi-major* axis of the elliptic orbit as well as its eccentricity e of a planet gradually and slowly change with time. The *semi-minor* axis(b) of the orbit is given by $b = a\sqrt{1-e^2}$ at any given time.

The actual distance (radius-vector) of a planet from the sun varies between the semi-minor axis b and the semi-major axis a. Accordingly, it is conjectured that the periphery of the *śīghra* epicycle varies (i) from $(360^0/a)$ to $(360^0/b)$ for a superior planet and (ii) from $(360b)^0$ to $(360a)^0$ for an inferior planet.

3 Moon's equations

In computing the position of the Moon, according to the *siddhāntic* texts, there has always been a noticeable deviation. The ancient Indian astronomers suggested the well known corrections, besides the *manda* equation, which we call *evection* and *variation.*

The equation of centre (*manda* correction) was known in India even before Āryabhata I (476 A.D.). In fact, Āryabhata himself gives the coefficient in the *manda* equation as $300'.25$. Brahmagupta in his *Uttara Khanda Khādyaka* gives the same as $301'.7$. However, it must be pointed out that out of the actual equation of centre, a part of it is combined with the second correction ("evection") and the combined equation is given in later *siddhāntic* texts.

In fact, this combined equation for the Moon was first given, among the Indian astronomers, by Mañjula (or Muñjala, 932 A.D.) in his *Laghumānasam.* P. C. Sengupta points out, "In form the equation is most perfect, it is far superior to Ptolemy's; it is above all praise." While the credit of discovering the Moon's second equation, among the Hindu astronomers, undoubtedly goes to Mañjula, it was Bhaśkara II (1114 A.D.) who introduced it into his *siddhānta.*

The third equation for the Moon's position, "variation" was introduced in Indian astronomy by Bhāskra II in 1152 A.D., four centuries before Tycho Brahe discovered it in the west.

The honour of introducing the fourth equation, to the Moon's position, now called *"annual equation"* goes to the highly dedicated astute astronomer from Orissa **M. M. Samanta Chandra Sekhar Simha** of the 19^{th} century. He called it *"Digamśa" samskāra* and incorporated it in his remarkable text, *Siddhānta darpana.* The constant coefficient in Chandra Sekhar's equation is $11'26dot6''$. It is important to note that Tycho Brahe had given the coefficient as $4'30''$. The modern value is $11'10''$. Thus, Chandra Sekhar Sāmanta's value is far closer to the modern value. This accuracy of his value is truly remarkable in the light of the fact that the Sāmanta was trained exclusively in the orthodox Sanskrit tradition and totally ignorant of the English education or the western development of astronomy.

The modern expressions for the three above-said equations of the Moon are as follows:

1. Evection $= 4586''\sin(2D - g)$ where $D = M - S$, the mean elongation of the moon (from the sun), M and S being the mean longitudes of the moon and the sun respectively and g is the mean anomaly of the moon (from its *perigee*).

In the context of Indian astronomy, the mean anomaly (*manda kendra*) is measured from the apogee (*mandocca*). If the perigee and the apogee of the moon are denoted respectively by P and A, then we have

Mean anomaly,

$$\begin{aligned} g &= M - P = M - (A + 180^0) \\ &= (M - A) - 180^0 \end{aligned}$$

so that the evection equation becomes

$$\begin{aligned} Evection &= 4586''\sin[2D - (A + 180^0)] \\ &= -4586''\sin[2D - (M - A)] \end{aligned}$$

However, as defined in the *Sūrya siddhānta,*

Manda anomaly = *Mandocca* - Mean longitude = A - M

in which case

$$\text{Evection} = -4586''\sin[2D + MA]$$

where $MA = A - M$, the *manda anomaly* of the moon. In terms of the mean longitudes of the sun (S) and the moon (M) the *mandocca* A, we have

$$\text{Evection} = -4586''\sin(M - 2S + A) \tag{5}$$

2. Variation

$$\text{Variation} = 2370'' \sin(2D) \tag{6}$$

where $A = M - S$, the moon's elongation from the sun. **Samanta Chandra Sekhar** in his *Siddhānta Darpana* has taken this equation as

$$\frac{[R \sin 2(M - S)]}{90} \text{ or } 38'12'' \sin 2D$$

$$\text{i.e. } 2292'' \sin(2D) \text{ where } R = 3438'$$

3. Annual equation $= -668'' \sin(g')$ where g' is the sun's mean anomaly i.e. $g' = S - P'$ [P' : Sun's perigee]

Here also, considering the sun's anomaly measured from his *apogee (mandocca)* A', as is the case in the *siddhāntas*, we have

$$\begin{aligned} \text{Annual equation} &= -668'' \sin[S - (A' + 180^0)] \\ &= 668'' \sin(S - A') \\ \text{i.e. Annual equation} &= -668'' \sin(A' - S) \end{aligned} \tag{7}$$

where $(A' - S)$ is the sun's *manda kendra* (as defined in the *Sūrya siddhānta*).
Remark: In fact, the moon's annual equation happens to be a fraction of the sun's *mandaphala* (equation of centre). According to the modern values of the concerned coefficients, we have

$$\text{Sun's equation of centre} = 6910'' \sin(g')$$
$$\text{Annual equation of the moon} = -668'' \sin(g')$$
$$\text{The ratio of the latter to the former} = -\tfrac{668}{6910} \approx -\tfrac{1}{10.34}$$

Samanta Chandra Sekhar has approximated this ratio to $-1/10$ and taken Moon's annual equation $= -\frac{1}{10}$ sun's *manda* equation.

As a respectful tribute to **Samanta Chandra Sekhar**, we shall continue to use the names *Tuṅgāntara, Pākṣika* and *Digaṁśa*, given by him, respectively for evection, variation and the annual equation.

Thus, from (5), (6) and (7), we have the three equations of the moon, besides the usual *mandaphala*, given by

1. *Tuṅgāntara Saṁskāra* (Evection) $= -4586'' \sin(M - 2S + A)$
2. *Pākṣika Saṁskāra* (Variation) $= 2370'' \sin 2(M - S)$
3. *Digaṁśa Saṁskāra* (Annual equation) $= -668' \sin(MK) \approx -\frac{1}{10.34}$ (sun's equation)

where MK is the sun's *manda kendra* (anomaly of apsis) defined by

$MK = A' - S$ (A': Sun's *mandocca*)

Note: In the *Tuṅgāntara* equation, given by **Samanta Chandra Sekhar**, a part of the (modern) equation of centre is combined with the evection equation. In the

earlier *siddhāntic* texts also, the *manda* equation included only a major part of the (modern) equation. However, in the proposed equations we are suggesting in this work, the three equations (1) to (3) above correspond to the three equations adopted in modern astronomy.

4 The case of Budha and Śukra

The traditional Indian astronomical texts have always treated Budha and Śukra differently from the remaining *tārāgrahas* viz. Kuja, Guru and Śani in the context of determining their true positions.

1. While the mean position of the superior planets are taken as they are, in the case of Budha and Śukra (the inferior planets) two special points called Budha *śīghrocca* and Śukra *śīghrocca* are considered.
   The position of the mean Ravi is itself taken as the positions of both mean Budha and mean Śukra. Again, while working out the *śīghra* equation, the argument of the relevant sine function is taken, for example in the case of Budha, as $(B - R)$ as per the *Sūrya siddhānta* convention, where B and R are respectively the Budha *śīghrocca* and the mean Ravi. In the case of superior planets, the order of the terms in the argument is reversed. For example, for Guru, the argument in the sine term of the *śīghra* equation is $(R - G)$ where G is the mean position of Guru. For the superior planets the mean Sun (Ravi) is considered as their *śīghrocca*.
   Nīlakantha somayāji (1444-1550 A.D.) points out in his *Tantra saṅgraha* that it is incorrect to have a differential treatment to the inferior and superior planets and that the sun is the common centre for the *śīghra* equation to all the planets. This is truly a remarkable breakthrough in the history of mathematical astronomy in general and in Indian astronomy in particular (see Ramasubramanian et. al., *Current Science*, May 1994). In fact, Nīlakantha's innovation, prompted by his *paramaguru* Parameśvara (1380-1460 A.D.), is highly suggestive of a heliocentric model of planetary motion, much before Copernicus. It is interesting that **Samanta Chandra Sekhar**, though independently, proposed a similar model (see **Siddhānta Darpana**, V, 6 and 7).
   Following the innovation introduced by the celebrated Kerala astronomer Nīlakantha, we propose the consideration of the *sīghra* anomaly in the same way for all the planets, namely

   $$\textit{Śīghra Kendra} = \textit{Śīghrocca} \text{ - Mean planet}$$

   (in the *Sūrya siddhānta* style) where the *śīghrocca* is the mean sun for all the planets.
2. In the case of Budha (Mercury), the major reason why its calculated true position, according to *siddhāntas*, goes generally off the mark is that the *manda* periphery taken for Budha *śīghrocca* by the *siddhāntas* is far below its actual modern value. The *manda* periphery, as prescribed in the *Sūrya siddhānta*, varies from 28^0 to 30^0 for Budha. But, actually, as pointed out in Table 3, the periphery of Budha's

manda epicycle should vary from about $109^0.8$ to about $184^0.7$. The coefficient of the *manda* equation depends on the eccentricity $\underset{\sim}{e}$ of the planet's orbit. In fact, the coefficient, to a first approximation is given by $2\underset{\sim}{e}$. In the case of Budha, $\underset{\sim}{e} =$ 0.205656 currently and hence the co-efficient of the *manda* equation turns out to be about $23^0.566$. In our proposed improved values for the parameters (vide Table 3) we have considered even higher powers of $\underset{\sim}{e}$ upto $\underset{\sim}{e}^5$ and the first two terms in the expansion for the equation of centre. Accordingly, for the beginning of 2000 A.D., the variation of the periphery of the *manda* epicycle is from $109^0 50' 46''$ to $184^0 47' 43''$ (depending on the varying *manda* anomaly). Correspondingly, the coefficient of the *manda* equation varies from about $17^0.48$ to $29^0.41$. In fact, our ancient Indian astronomers had not taken note of the fact that among the planets known to them, Budha's orbit has the largest eccentricity. This lapse explains why Buudha's true position always remained an enigma to them despite all the *bīja samskāras* introduced by them. Of course, now after the discovery of the three trans-saturnine planets, Pluto's orbit has the largest eccentricity (0.2488723) while the immediately next is Mercury's orbit (0.205656).

5 Mean positions of bodies at Kali epoch

The mean positions of the sun, the moon (with its *mandocca*, anomaly from the apogee and the ascending node, Rāhu), and all the planets, upto Pluto, at the Kali epoch (mean midnight between 17/18 February 3102 B.C. at Ujjayini) are computed according to modern formulae. The *sāyana* (tropical) as well as the *nirayana* (sidereal) longitudes are listed in Table 5. The mean *ayanāmśa* adopted for the Kali epoch is $-46^0 34' 52''$ based on the recommendations of the Calendar Reform Committee of the Govt. of India.

Table 5. Mean positions of bodies at the Kali epoch

Date (Roman) :	18 / 2 / - 3101
Time (IST) :	0 Hours 27 Minutes (local midnight)
Place:	Ujjayini
Longitude :	75^0 46′ E
Latitude :	$23^0$11′ N
Julian Days :	588466 Weekday: Friday

Note: If the weekday before the sunrise is considered as of the previous day, then it is a thursday as in the case in the Indian traditional reckoning. *Ayanāmśa* is the amount of precession of the equinox since 285 A.D.

Note: In Tables 5 and 6, (i) Apogee is the *mandocca* and the anomaly (Anom.) is the

⋆ Mean longitudes of planets ⋆ Ayanāmśa: $-46^0 34' 52''$

Body	*Sāyana*			*Nirayana*		
	D	M	S	D	M	S
Candra	297	41	10	344	16	2
Apogee	66	31	36	113	6	28
Rāhu	142	12	36	188	47	28
Ravi	301	37	54	348	12	46
Apogee	15	59	32	62	34	24
Śukra	333	52	43	20	27	35
Budha	267	27	27	314	2	19
Kuja	289	2	33	335	37	25
Guru	26	41	57	73	16	49
Śani	349	49	59	36	24	51
Uranus	344	50	57	31	25	49
Neptune	250	1	11	296	36	3
Pluto	317	21	11	3	56	3

Table 6. Mandoccas of planets at the Kali epoch

⋆ Mean Mandoccas (Apogees) of Planets ⋆ Ayanāmśa: $-46^0 34' 52''$

Mandocca	Tropical			Sidereal		
of	D	M	S	D	M	S
Candra	66	31	36	113	6	28
Ravi	15	59	32	62	34	24
Kuja	109	2	33	155	37	25
Budha	178	5	2	224	39	54
Guru	191	54	28	238	29	20
Śukra	293	54	36	340	29	28
Śani	325	46	24	12	21	16
Uranus	349	2	35	35	37	27
Neptune	70	1	11	116	36	3
Pluto	333	0	18	19	35	10

manda kendra measured from the apogee; (ii) in the case of Budha and Śukra, the mean positions of the planets themselves are considered and not as their *śīghrocca*. As pointed out earlier, the mean sun is now the *śīghrocca* for all the planets; (iii) the *Sūrya siddhānta* has taken the moon's *mandocca* at the Kali beginning as 90^0 while our modern computation for the *(nirayana) mandocca* brings it to $113^0 6' 28''$.

Table 6 provides the *mandoccas* (*nirayana* apogees / aphelions) at the epoch, the beginning of the Kaliyuga.

6 Revolution of bodies in a Kalpa

In Table 2, we have provided the numbers of revolutions (rounded off to the nearest integer) executed by the heavenly bodies and the special points in the course of a *Mahāyuga* of 432×10^4 years. However, to get more accurate values for the mean

positions of the bodies we have listed the numbers of revolutions in a *Kalpa* (432×10^7 years) based on the modern known rates of (sidereal) motion of these bodies in Table 7. In this table the revolutions of the (sidereal) *mandoccas* of all the planets, including Uranus, Neptune and Pluto, are also provided.

Table 7. Revolutions of bodies in a Kalpa

Grahas	Revolutions of *Grahas* our porposed values	Chandra Sekhar	Revolutions of *Mandoccas*
Chandra	57,75,29,85,910	57,75,33,36,000	48,81,25,074
Ravi	4,32,00,00,000	4,32,00,00,000	38,777
Budha	17,93,70,33,867	17,93,69,67,141	19,134
Śukra	7,02,22,60,402	7,02,22,57,860	1,439
Kuja	2,29,68.76,453	2,29,68,71,112	53,367
Guru	36,41,95,066	36,41,55,205	25,671
Śani	14,66,56,219	14,66,49,716	67,486
Uranus	5,14,16,997	-	10,607
Neptune	2,62,19,242	-	3,424
Pluto	1,73,90,083	-	214
Rāhu	23,22,68,618	23,22,98,033	-

7 Conclusion

In the preceding pages we presented a comparison of the values of the parameters and our suggested *bījas* (corrections) in respect of the computations of mean and true positions of the planets. Of course, the comparative study as well as the suggestions for improvements are made within the style and framework of the *Siddhāntic* tradition. **Samanta Chandra Sekhar's** improvisations are also highlighted in relevant places. We propose to continue our studies to work out further sharpening of the *bījas* for obtaining reasonably good values in computations of planetary positions as well as eclipses.

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Outstanding Achievements of a Nineteenth Century Indian Astronomer and Similar Achievements of an Ancient Chinese Astronomer*

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1 Life

Samanta Chadra Sekhar was born on 13 December in 1835 A.D. in a small village named Khandapara in the State of Orissa in India. At an early age, Samanta received instruction in the language Sanskrit. At the age of ten, one of his uncles taught him a little of astrology. He was shown some of the stars to satisfy his curiosity. Gradually Samanta became curious about the movement of planets among the stars in the sky, and this initiated him to study astronomy. But there was no teacher, who could instruct him in this discipline of science.

At the age of fifteen, Samanta came to learn the rules for calculating ephemerides of planets with the help of old Sanskrit *Siddhāntas* (treatise on astronomy). He was surprised to notice much difference between the calculated position of a planet with the aid of the principles laid down in the old *Siddhāntas* and the corresponding observed position. To obtain the observed position of a celestial body more accurately, Samanta started making for himself a few primitive instruments for measuring time and angular distances between the celestial bodies in the sky. It has to be noted here that, during his time, the orthodox astronomers refused to believe in the existence of any error which might have crept into the figures of the old *Siddhāntas* in course of time. Moreover, the use of foreign nautical almanacs for regulating the religious observances was completely out of the question. In this context, Samanta made a revolution in finding reasons for introducing corrections in the formulae given in the age old *Siddhāntas.*

And his purpose was so simple as making calculations agree with observations. He was an adherent of truth obtained by direct observation, and would not hesitate to denounce any religious authority, if a proof to the contrary was obtained. At the age of twenty-three, Samanta began to note down systematically the results of his astronomical observations, and three years later, this outcome was his monumental

* (Based on the paper presented by the author at the International Symposium on "Astronomical Exchange between China and other Countries" held at Beijing on 16th September, 1997)

work of *Siddhānta-Darpana* which contains 2500 verses in Sanskrit. Thus *Siddhānta-Darpana* is an *extra-ordinary treatise* for showing errors in India's traditional age-old almanacs. This was originally written on palm leaves in Oriya script. Of these, 2284 verses were composed by Samanta and the remaining 216 quoted from the old *Siddhāntas* like the *Surya-Siddhānta* and the *Siddhānta-Siromani.*

But it is really tragic that such a talented astronomer of India remained unknown to the world of science till 1899 when his *Siddhānta-Darpana* was published from Calcutta with an introduction by Jogesh Chandra Ray, the then Professor of Physical Sciences of the Ravenshaw College of Cuttack, the then Capital of Orissa.

This famous treatise only then came to the notice of the western world and the famous British scientific journal "Nature" wrote: "Professor Ray compares the author to Tycho Brahe. But we shall imagine him greater than Tycho" (Nature Vol. 59, No. 1532, March 9, 1899, pp 436-437).

And what did Samanta receive from his own country ? He met with sneers from his equals in position, because he shook off the aristocratic prejudice against star-gazers and fortune-tellers with the revolutionary methods of observations of celestial bodies with the aid of instruments constructed by himself. He had no one to encourage him in his pursuit and no notice was taken of his work. Samanta expired on 11 June, 1904 at Puri, the holy city of Orissa.

2 Instruments

Samanta was always of the opinion that arguments could never defeat the results of direct observation. Correct observation was the only test to settle down the question. He constructed a few primitive instruments for measuring time and angular distances between celestial objects.

Samanta's observational equipments consisted of an armillary sphere and a vertical wheel as substitutes for modern transit and alta-azimuth, and the time honoured clepsydra took the place of the sidereal clock. Of course, the all-useful gnomon found a place in his observatory. The instrument, of which he made constant use, was one devised by himself and he called it as *Mana Yantra* (i.e. measuring instrument). In fact, *Mana Yantra* consisted of a thin rod of wood, twenty four digits long, at one end of which is fixed another rod at right angles in the form of a 'T'. The cross-piece is notched and also pierced with holes at distances equal to the tangents of the angles formed at the free extremity of the other rod. Of course, this was, no doubt, a crude instrument which did not admit of being so divided as to enable him to measure a degree with any accuracy.

Some of the instruments used by Samanta are now preserved in the Samanta Chandra Sekhar Gallery of Orissa Govt. Museum at Bhubaneswar, present capital of Orissa.

3 Main computational works

1. **Sidereal Periods**
   – Computed sidereal periods in mean solar days of the Sun, the Moon and five planets. In respect of planets, Samanta's advancement is truly remarkable.
2. **Mean Inclinations**
   – Mean inclinations of the orbits of the planets to the ecliptic were computed. His results have been found to closely agree with modern astronomy.
3. **Moon's Inequalities**
   – Samanta was the only Indian astronomer who detected three very important irregularities of the Moon viz. Evection,k Variation and Annual Equation.
4. **Horizontal Parallax of the Sun and the Moon**
   Samanta's value of Sun's horizontal parallax = $22''$, and that of Moon's horizontal parallax = $56'28''$.
   The Moon's parallax almost agrees with its modern value.
5. **Longitudes of Planets**
   Samanta computed the longitudes of the Sun, the Moon and five planets for 6p.m. local time of Cuttack on 31 January 1894.

   Error in traditional almanacs from modern values = 4^o, (about)
   Error of Samanta from modern values = $\frac{1}{2}^o$ (about)

4 Conclusion

Samanta Chandra Sekhar occupies a pre-eminent position amongst the galaxy of great astronomers that India produced over the centuries. He was able to track the stars and planets with his own devices when the sophisticated science of astronomy had not developed in India by modern standards. He was completely unaware of the European discoveries in astronomy. To appreciate Samanta, one must compare his work with other works produced under similar conditions. Moreover, poverty did always pinch him and it compelled him to incur a large debt at his old age. He received no financial assistance for his observational efforts. Samanta made numerous observations to test every figure used in the age-old *Siddhāntas*, in order to see, if it remained true or not. He did not make any compromise with errors in *Siddhāntic* astronomy – this high quality of very bold and original way of thinking may be found only in a man of genius of extraordinary merit. Even with very limited resources, he could make improvement in the determination of a good number of astronomical elements found in error in our ancient *Sïddhāntas.*

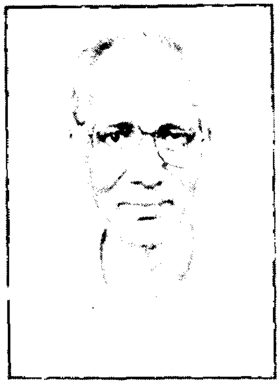
5 Comparison of Samanta with a Chinese Astronomer

Efforts of Samanta Chandra Sekhar for correction of formulae, enunciated in old astronomical treatises of India, for the purpose of making calculations agree with observations, may be compared with those of an ancient Chinese astronomer Shen Kua

(1031 - '95). Shen constructed a set of improved astronomical instruments, including a gnomon for solstice measurements and an armillary sphere. Shen proposed a purely solar calendar in place of the luni - solar calendar that had been in use in China from ancient times. He was right in supposing that it would give offense, and radical reform was not to come until the mid nineteenth century. China finally adopted the western (Gregorian) calendar for most public purposes in 1912.

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Venture to Samanta Chandra Sekhar and His Impact on Present Time

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I am deeply grateful to the organizers of the Institute of Orissan Culture and Samanta Chandra Sekhar Amateur Astronomers' Association for inviting me here and to present a paper on an illustrious son of Orissa, nay India, namely Samanta Chandra Sekhar.

At the outset, humbly I submit my ignorance in astronomy, astrophysics or mathematics, because I am a teacher of Physiology the subject that deals with human body and systems, and maintains a polar gap from astronomical affairs. However, I will discuss something, in short, about Samanta Chandra Sekhar, though I will restrict my discussions only on three points; (i) my venture to Samanta Chandra Sekhar, (ii) some characteristics of Samanta Chandra Sekhar and (iii) projection of slides regarding Chandra Sekhar.

(i) Some twenty years back from now, by chance I became interested about an astronomer(Radha Gobindo Chandra), who was almost unknown in our country. I tried to trace him out from dark. While I was searching, there I came across the name of Samanta Chandra Sekhar in connection with almanac system. Henceforth, I became interested to know about him, and surprisingly, I find that the educated Bengalees and even those who are attached to astronomy in Calcutta, are almost unaware about Chandra Sekhar.

From then on, I had to collect the materials about Chandra Sekhar. The Calcutta National Library Oriya Section, provided me various informations and materials. In search of materials I came to Orissa in 1991, visited his native village Khandapara, took photographs of his house he lived and his mementos that lay there. Also, I collected the whole text of the introduction written by Prof. Jogesh Chandra Roy in the book *Siddhānta Darpana* of Samanta Chandra Sekhar. Moreover, I brought the valuable reviews of *Siddhānta Darpana* that were published in the famous journals like Nature and Knowledge of London.

In this way, after being enriched myself about Chandra Sekhar, I started to write about this astronomer in the magazines like "*Jnan O Bijnan*" (monthly science journal), *Desh* (fortnight) etc. Also, I did a programme in Doordarshan, Calcutta about Samanta Chandra Sekhar.

(ii) Dear scholars, I am not going to elaborate here the life and works of Chandra Sekhar in detail, but I like to mention some of the characteristic points that we can put forward for the future generations.

It is too often assumed that nothing in astronomy can be achieved without the possession of a telescope. The observational equipments of Chandra Sekhar were in

no way superior to those of an astronomer of pre-telescopic age, and the results he obtained were almost at par with the modern astronomers.

At present, it is said that to win real achievement in the field of science one has to go abroad. At least scientists like Prof. Satyen Bose and J. B. S. Haldane did not share this notion, which stands refuted by the story of Samanta Chandra Sekhar's life and struggles. Chandra Sekhar had no formal education, no foreign training and never possessed an well equipped observatory.

Prof. Jogesh Chandra Ray in his Introduction of *Siddhānta Darpan* has depicted a beautiful picture of the observatory of Chandra Sekhar. He wrote :

"It was the clear blue vault of the heavens that was his observatory"

Instead of all odds, Chandra Sekhar made remarkable contributions in the field of astronomy.

Prof. Jogesh Chandra further compared Chandra Sekhar to Tycho Brahe, who is considered as the father of the modern astronomy and the reviewer of the famous journal Nature took the point very aptly by saying:

"Prof. Ray compares the author very properly to Tycho. But we should imagine him to be a greater than Tycho, for without the same assistance, without the encouragement of kings and the applause of his fellows, he has advanced his favourite science ..."

The observations made by Chandra Sekhar can be considered as a landmark in the history of Hindu astronomy. His painstaking labour and patience help to have a correct almanac. Since 1876, the famous Puri temple follows the almanac computed by Chandra Sekhar.

The name of Chandra Sekhar was very rightly choosen in the book 'Astronomy without Telescope' by E. W. Maunder (1904), where the author said:

"In the recluse of the Orissa village we see to have reincarnated as it were, one of the early fathers of the science, long centuries era the telescope was dreamt of, as he grappled with the problems, which the planetary movements offered him for solution"

It is a matter of regret even after fifty years of independence, we cannot develop a scientific temper among the greater mass of the country. It is the scientists, most of them are western oriented who maintained a gap with the common people. Mentionably, non-formal scientists like Chandra Sekhar are common man. So that the people can consider them as their own and also they can understand that with utmost devotion, perseverance and scientific outlook any one can contribute in the field of science.

So, in the science movement, astronomer like Chandra Sekhar can be choosen as an ideal, and we should consider him as one of the pioneers amongst the modern observational astronomers. Also, we can consider his life a beacon to every serious voyager in the domain of science and knowledge.



K. Srinivasa Rao (b. 1942) had his school and university education in Madras. Studying in Vivekananda College and Presidency College, he received his B.Sc. (Hons.) (1961) and M.Sc. (Physics) (1963) respectively from Madras University. He carried our research in intermediate energy nuclear physics at Institute of Mathematical Sciences (IMSc.) and got Ph.D. from Madras University in 1972. He joined IMSc. as Assistant Professor in the same year and rose to the position of full Professor in 1989 and Senior Professor in 1997. As Alexander Von Humboldt Fellow, he has carried out research at University of Bonn, and Technical University of Clausthal, Germany. He has worked as visiting/guest scientist at University of Texas at Austin, USA; Rijks University, Belgium; Duke University, USA; Daresbury Laboratory, Uk; and Rensseler Polytechnic Institute, Troy, New York etc. He is recipient of Tamil Nadu Scientists Award and Popularisation of Science Award of Government of Tamil Nadu. He is Fellow of National Science Academy, India and Tamil Nadu Academy of Sciences.

Indian Astronomy: A Sketch

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Indian astronomical works date back to Aryabhata's *Aryabhatia* (499 A.D.), Brahmagupta's *Brahmasputa-Siddhanta* (7th Century A.D.), Bhaskaracharya's *Siddhantasiromani* (1150 A.D.) and Nilakantha Somayaji's *Tanatrasangraha* (1500 A.D.). These major works influenced the development and growth of Astronomy in our country. The influence of the Persians and the Greeks can be seen in some of these early works based on the medieval geocentric system.

By the 9th century A.D. the Aryabhatia and the Brahmasputa-Siddhanta were translated into Arabic. The great mathematician-astronomer Al-Khwarismi (780-858 A.D.) belonged to this period. With the Islamic rule, Arabic/Persian astronomy found its roots in India.

The *Tantrasangraha* which is 500 years old presents a systematic exposition of Indian astronomy in verse form, containing results on the computation of the velocities of the planets, of eclipses and other quantities in spherical astronomy. Nilakanta who belonged to the Kerala School of Astronomers, also discussed a geometrical picture of planetary motion, according to which while the planets Mercury, Venus, Mars, Jupiter and Saturn execute eccentric orbits around the Sun, the Sun itself goes around the earth. This model is the first departure from the geocentric Ptolemy model of the Solar system, according to which all the planes of the planetary orbits intersected at the Earth, which made it much more difficult to study the motions of the planets. The Indian astronomers were able to compute the latitudes of the planets with this model which was a departure from the geocentric model. In the 19th century, Samanta Chandra Sekhar, a reputed astronomer in Orissa, arrived at a geometrical picture which is similar to that of Nilakantha Somayaji and he obtained important corrections to the lunar motion. In March 2000, the Department of Physics, University of Madras, organized a 3-day conference on: *500 Years of Tantrasangraha: A Landmark in the History of Astronomy.* Diverse aspects of Nilakantha's works in the context of the development of Indian Astronomy were discussed by experts at this meeting.

There has been a popular feeling that not much significant work came out of India in astronomy and mathematics after the period of Bhaskaracharya and Bhaskara. Sawai Jaya Singh II (1686 - 1743), born in Amber, revived interest in Astronomy by building observatories in Delhi, Jaipur, Mathura, Ujjain and Varanasi. The *Jantar Mantar* built in 1724 A.D. with large stone structures housed a wide variety of instruments and it has been preserved for posterity as a heritage monument. The

geocentric system was still the model in India, even though Copernicus(1473 - 1543) had introduced the heliocentric system, in Europe, about two hundred years earlier.

Though at the end of the 17th century the Jesuit priests brought the telescope to their settlement in Pondichery, it was the British merchants who brought astronomical instruments and set up the first observatory in Madras. The plaque on this observatory proclaims: *Posterity may be informed a thousand years hence of the period when the mathematical sciences were first planted by British liberality in India.* The observations at Madras led to the discovery of a new variable star R.Reticuli in the southern sky in 1867. A catalogue of 11015 southern stars was produced by G. Taylor from Madras after almost two decades of careful observations.

By 1899, the British set up the Kodaikanal Observatory for solar observations. Using a specially built instrument, John Evershed made the important discovery of huge vertical motions of gases in sunspots, in 1909. This has been christened as the Evershed Effect. The Kodaikanal observatory now houses a new solar telescope acquired in 1958 and has an invaluable collection of solar photographs covering eight solar cycles. A crater on the invisible side of the moon was named, in the International Geophysical Year (1957-58), after Dr. A.K. Das, who was the Director of the Kodaikanal Observatory at that time.

A private observatory was started, at the beginning of the 20th century, by the Nawab Zafar Jung in Hyderabad. Being an enthusiastic astronomer, he photographed and charted a large segment of the sky. The observatory was named the Nizamia but was soon taken over by the Government and in later years shifted to a new building in the Osmania University campus. In 1968, when a 40 inch reflector telescope was acquired, it was erected at a site named Japal-Rangapur, not far from Hyderabad. Today both these sites are under the supervision of the Osmania University.

Though a few other observatories came into existence in Lucknow (1832) and Thiruvananthapuram (1836), they have not survived. So, in the British period many attempts were made to start astronomical observatories but only the Kodaikanal and the Hyderabad observatories survived till date. The renowned American astronomer Dr. Harlow Shapely when he came to India in 1947 lamented about the meager facilities for experimental astronomy. At that time, the young Vainu Bappu who was eager to pursue a career as an astronomer and whose father was as astronomer at the Nizamia Observatory, came into contact with Dr. Harlow Shapley, and this opened up an opportunity for Vainu Bappu to go to Harvard, on a Government of Hyderabad scholarship, in early 1949. The discovery of a comet, named the *Bappu-Bok-Newkirk Comet*, and the discovery of fundamental relations used in determining a star's luminosity, called the *Wilson-Bappu effect*, established him as a front ranking astronomer of the day.

Bappu returned in 1953 after gaining valuable experience with research using the 200-inch Palomar telescope, then the largest in the world. Initially he established a new observatory at Manor Park in Nainital and groomed a team of astronomers there, before moving to Kodaikanal Observatory in April 1960. A large observatory was recommended by Meghnad Saha and his committee of experts, in 1945 and the responsibility of setting up one such was taken up by Vainu Bappu. A search for a suitable location culminated in his selecting the present Kavalur (North Arcot, Tamil Nadu) site in the Javadi Hills, where an indigenously built 38 cm telescope was commissioned in 1967. Five years later, a one meter Zeiss telescope was installed in Kavalur. Major discoveries made at Kavalur are: the discovery of a trace of atmosphere on Gynymede, the largest satellite of Jupiter; and the rings of Uranus. Vainu Bappu was elected Vice-President (1967-73), as well as President (1979-82) of the International Astronomical Union (IAU). The indigenously built 2.3 meter (93 inch) telescope at Kavalur was set up in 1985, three years after the death of Vainu Bappu who planned it. In 1985, the IAU Assembly was held in India - a recognition for the advanced research facilities assiduously built by the astronomers of independent India. During this assembly a newly discovered asteroid was named after Vainu Bappu. A year later, in 1986, the Kavalur Observatory and the largest (2.3 meter) telescope in Asia were both named after its founder, Vainu Bappu.

An observatory in Nainital has a one meter reflector telescope; an observatory in Mount Abu has a 1.2 meter Infrared telescope; a solar observatory at Udaipur (in an island in Fatehsagar lake) has three telescopes to study helioseismology and to make chromospheric observations. The Mt. Abu and Udaipur observatories are now a part of the Physical Research Laboratories, Ahmedabad.

The untiring efforts of the radio astronomer Govind Swarup, resulted in the design, fabrication and erection of the 530 meters long, 30 meters wide Radio Telescope, in 1970, in the picturesque Ootacamund (Uthagamandalam) hill station in Nilgiri Hills. The Ooty Radio Telescope, the largest of its kind, has been used for the study of radio sources, pulsars and supernova remnants. A cluster of smaller radio telescopes on the Nilgiri hills was used for radio interferometry studies. Besides Ooty, radio astronomical facilities are also available at Ahmedabad, Bangalore, Gauribidanur and Khodad. The world's largest radio telescope named the Giant Meter-wave radio Telescope (GMRT) has been erected near Khodad (about 80KM north of Pune), in 1995. The GMRT has been set up to realize two important objectives, viz.: to detect the highly red shifted spectral line of neutral hydrogen (1420 MHz) expected from protoclusters or protogalaxies before they condensed to form galaxies in the early phase of the Universe; and to search for and study rapidly rotating pulsars in our galaxy.

In the allied field of Astrophysics, India made significant contributions. Most significant of these being the ionization formula of Meghnad Saha and the exhaustive studies of stellar evolution using the special relativity theory by S. Chandrasekhar

and his discovery of what has since become famous as the 'Chandrasekhar limit' for the size of a white dwarf star to collapse into a black hole after it has burnt up all its energy. Homi Bhabha and Alladi Ramakrishnan made significant theoretical contributions in the study of Cosmic ray shower phenomenon. In 1988, Jayant V. Narlikar was entrusted by the University Grants Commission to set up the Inter-University Center for Astronomy and Astrophysics (IUCAA), to promote nucleation and growth of active groups in Astronomy and Astrophysics in Indian Universities.

The industrial house of Birla took the initiative to set up Planetariums. Between 1954 and now there are about 30 planetariums in the country, where many interesting astronomy programs are presented on a day-to-day basis. Bangalore, Chennai, Hyderabad, Mumbai and Thiruvananthapuram host besides the Planetariums, Science and Technology Museums[1]. Generations of school children and college students are benefited by these Planetariums and Museums.

In fine, Independent India has created not only excellent research centers for Astronomy and Astrophysics but also set up Planetariums and Science and Technology Museums for disseminating knowledge to students and public. The reader who has an access to the internet (Netscape or Explorer) is urged to go through any one of the search engines, like Google or AltaVista, and try out searches for "Indian Astronomy" or "Astronomy" to start the exploration of a world of information. A representative sample of these web sites of institutes / observatories is given below and these have also been the sources for this article. The author acknowledges with thanks the creators of these sites:

References

1. For Gunakar Muley's informative article '*Indian Astronomy: From Jantar-Mantar to Kavalur*' refer:
   www.vigyanprasar.org/dream/dec99/article1.htm
   This has been a source for some of the details in the present article.
2. Astronomical Society of india: www.rri.res.in/asi
3. Inter-University Center for Astronomy and Astrophysics:
   www.iucaa.ernet.in
4. Indian Institute of Astrophysics: www.iiap.ernet.in
5. Mount Abu Observatory: www.prl.ernet.in/astronomy/irtel
6. Udaipur observatory: www.uso.ernet.in
7. Institute of Mathematical Sciences: www.imsc.ernet.in

[1] In the Periyar Science and Technology Center in Chennai, the author's *πie Pavilion*, *Ramanujan Museum* (Replica) and *Ramanujan Photo Gallery*, created for the Indian Science Congress Exhibition 1999, with financial support from the Department of Science and Technology, Government of India, have been housed.



Manoj Kumar Pal (b.1932) had his school education in a village school in Nadia district - now in Kustia district of Bangladesh from where he passed Matriculation examination of Calcutta University (CU) in 1947. Then he moved to Calcutta where he had all his university education under Calcutta University. He passed B. Sc. (Hons.) (1951) and M. Sc. (Physics) (1953) studying at Presidency College and Science College (CU) respectively. Soon after he joined Saha Institute of Nuclear Physics and carried out research in theoretical nuclear physics leading to his Ph.D. in 1959. He joined the faculty of Saha Institute of Nuclear Physics in 1960 and rose to the position of full Professor in 1969 and Senior Professor in 1981. He became the Director of this Institute in 1983 and continued in this position till his retirement in 1992, thereupon he served as Emeritus Scientist of CSIR, Government of India till 1997. He has worked as visiting scientist/professor in many reputed institutes and universities in abroad including Princeton, MIT, Oxford, Manchester, ANU (Canberra) and KFA (Juelich) etc. He has acted as the Co-Director of the International Workshops/Schools in Nuclear Physics at International Centre for Theoretical Physics, Trieste, Italy for sixteen year (1969-85). He is elected Fellow of Indian National Science Academy and Indian Academy of Sciences.

History of Ancient Civilisations and the Development of Astronomy

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1 Introduction

Curiosity of the world around him is an inherent trait of the human being and seeking a categorisation and explanation of observed phenomena is an innate attribute of man's richly endowed brain. It, therefore, stands to reason that primitive men, after having achieved a modicum of social organisation wherever they thrived, must have taken a profound interest in the luminous objects on the vault of the sky, the innumerable 'tiny' dots of light and the two 'large' discs - the moon going through its regular phases in the course of roughly thirty nights and the blazing sun rising and setting everyday, its dazzling light revealing the environment and thus making it possible for them to carry out all their essential activities for food gathering, crop production and other necessary social management and interactions. They must have also gazed with awe at the strange phenomena of the eclipses of the moon and, more so, at the less frequent eclipse of the sun which frighteningly converted days into nights. No wonder they had ascribed an inexorable power to these heavenly bodies - a power that, they thought, influenced their own well being on earth and had, therefore, to be kept pleased by unstinted obeisance, devout prayers and costly offerings. Nevethless, the class that specialised in these rituals and forecasts - the rudiments of Astrology - also steadfastly pursued the observation of the sky and developed considerable professional skill in recording their primitive data and recognising important systematics in them. Such experiences, accumulated in the primitive human societies, laid the foundation of Astronomy, recognised now as the very first scientific discipline created by man.

I shall specifically deal with the astronomical knowledge mastered by the old civilisations of: (i) Egypt, (ii) Sumeria, Babylonia, Chaldea and Assyria, lumped together because of their geographical contiguity and locational overlap - all contained within the sovereign jurisdiction of present day Iraq and Kuwait, (iii) India and (iv) China. The contributions of (v) the Greeks (vi) Romans and (viii) the Arabs will also find a significant place in this presentation.

I shall trace the history of these ancient civilisations somewhat in juxtaposition with one another, to faithfully preserve their mutual interactions and overlaps. I shall start, in each case, with the remotest dates when the particular civilisation had entered into historical records and then proceed to a date roughly in the first few centuries of the Christian era. I choose this terminal point because I wish to restrict myself to developments in Astronomy upto an age when the optical telescope was not invented and only simple devices were used for astronomical observations. This choice,

although arbitrary, is in keeping with the spirit of this occasion, namely, recalling the hallowed memory of Samanta Chandra Sekhar, a self-taught prodigy and perhaps the last pre-eminent master of the traditional Indian Siddhānta School of Astronomy. This great genius, during his active life, had very little access to the wide world beyond the limits of his own rural surroundings and enjoyed only the benefits of his family library to drive his knowledge and inspirations from. For astronomical observations he had to restrict himself only to simple instruments, described in Siddhānta texts, with his own innovations and alterations in design. I take this opportunity to pay my homage to Samanta Chandra Sekhar and wish that the Association bearing his name will prosper with time and continue to achieve its aims and objects in a meaningful way.

It is well known that the heliocentric picture of Copernicus, Galileo's use of a telescope to observe heavenly bodies, particularly the motion of the satellites of Jupiter, Newton's theory of gravitation and his mathematical derivation of the planetary motion ushered in the new age of Astronomy. As I have said, all this will be outside my purview. However, to enthuse the young students I feel tempted to make a few observations on the extremely fascinating developments in the subject at the present time (modern age) starting in the sixties of the present century. Much earlier in this century the application of optical spectroscopy to the visible light received from the stars (the sun included) gave vital informations on the chemical elements present in these bodies, their surface temperature and several other physical properties. M. N. Saha's work on thermal ionisation played a major role in the correct interpretation of the observed data and, truly speaking, gave birth to the subject of Astrophysics as an important and fundamental adjunct to observational Astronomy. Physics of the evolution of stars and galaxies ultimately led to serious queries about the beginning and evolution of the whole universe, now passing under the brand name of Cosmology. The methods of observations related to these allied fields - Astronomy, Astrophysics and Cosmology - have undergone a tremendous expansion -cum- versatility and incorporated the highest sophistication of present day optical, electronic and computer technology. Improvements in optical telescopes have meant going for bigger and bigger ones with wider and wider apertures to increase the light gathering capacity and the power of resolution between two very close lying images. Ordinary photographic recording has also been superseded with the aid of CCD's (charge coupled devices) that generate a mosaic of electric charge which is fed to a computer to produce an image. What is more important, new detecting devices have been employed to cover signals from the sky in the entire range of electromagnetic radiation. Starting from radio telescopes in different wave bands on the high wavelength side, one now uses infrared and ultraviolet on the two extremes of the optical range, and X-ray and gamma-ray spectroscopy on the short wavelength end. To avoid the problem of absorption by our atmosphere, X-rays and gamma-rays in particular, are detected in satellite based laboratories set up beyond the atmospheric belt. In each of these methods the entire sky is scanned extensively and individual objects of interest sending the

specific type of radiation are also intensively studied. As a result of these proliferated techniques of observation many interesting phenomena have been newly discovered: (1) a uniform background radiation coming isotropically from all directions of space corresponding to a temperature of nearly $2.7^0 K$ if it is treated as black body radiation in equilibrium. It is interpreted as the cooled remnant of the electromagnetic radiation originating at the time of creation of the universe in a big bang ; (2) in addition to 'seeing' many distant galaxies, clusters of galaxies and individual stars of the main sequence (our sun is one of them), red giants, variable stars, binary stars, nova and supernova and white dwarfs-all outside the main sequence-observations have been made on new kinds of objects like (a) intense radio galaxies, quasi-stellar objects each with a total energy output many thousand times more than the usual galaxies where nucleosynthesis is the main source of stellar energy, and (b) neutron stars (radius of the order of 10 km and density $\approx 10^{12} kg/cc$), also called pulsars because they emit radio pulses at very precise intervals of time ; (3) indirect evidence of black holes (very small radii, 3 km and less, and extremely high density) in each of which the very strong attractive gravitational force does not permit even light to escape from its interior, and any material object approaching it close enough to a critical radius (the event horizon) from its center is pulled in (hence the name black hole).

Theoretically some of these phenomena and the early cosmological history require the application of the general theory of relativity and even a quantised version of it along with many subtle aspects of the theory of elementary particles and gauge fields. Altogether it has been a very attractive area of research. Had I been much younger, I would have certainly opted for it. As a serious beginning in self education I delivered a student-level course of lectures on the General theory of Relativity and Cosmology during a recent visit at the Institute of Physics (IOP), Bhubaneswar. I also delivered two semi-popular lectures at IOP with the hope that these would evoke some interest in ancient history as well as early Astronomy growing in the cradle of ancient civilisations. The first of the two lectures was delivered under the auspices of the Samanta Chandra Sekhar Amateur Astronomers' Association and the second was devoted mainly to ancient civilisations and the growth of science, in particular, the rudiments of Astronomy. The article presented here is an amplification of the two-lecture series.

2 Ancient Civilisations

2.1 Early Egypt and Sumeria

Civilisations of Egypt and Sumeria date back to nearly the same period in antiquity. Organised human societies based on agriculture and small crafts had evolved before 4000 BC in Egypt on the banks of Nile and close to the Persian gulf in Sumeria, the land between the two rivers Tigris and Euphrates, presumably because of the ease with which people could raise a crop in both these places. The Nile got flooded very regularly every year inundating a vast area on both sides. When the flood water

receded, it left a rich crust of silt on the land, yielding very easily, an abundance of harvest. In Sumeria and Babylonia the ancient people, very resourcefully, built a network of canals from the two rivers and learnt how to use the irrigation water as an aid to agriculture. The people of both Egypt and Sumeria had produced written languages of their own as early as 3500 BC. About the same time organised political authority had also arisen after subjugating and controlling local tyrants who thrived for a time in all primitive human societies. According to records, the 1st dynasty of Egyptian rulers got themselves established around 3400 BC at Memphis in the Nile delta. In the course of time, later ruling dynasties controlled, more or less, the entire geographical area on the two banks of Nile from the delta in the north to the Sudanese highlands in the south. In Sumeria the political and military authority at an early stage was also vested in dynastic kings but each king exercised his sway only over his own city state. The city of Uhr, as archaeological findings suggest, was a leading city state located to the south of the confluence of the two rivers before the combined stream met the Persian Gulf. The city of Babylon, which came to prominence many centuries later, was located farther north on the river Euphrates, and Nineveh which became the capital city of the Assyrians much later, was up the Tigris (lying to the east of Euphrates) several hundred miles in the north from Babylon. In their hey-days the rulers of Egypt as well as Babylonia/ Assyria / Chaldea established huge empires - Egypt making inroads into Asia and the other expanding to the west up to the Mediterranean. Small and weak countries (at the particular point of time when each invasion came) like Levant - the land of the Phoenicians along the Mediterranean coast (Tyre, Sidon etc. were their city states) - Syria and Israel (the land of the Jews, the people of Abraham) all along bore the brunt of these conquests as buffers. Several times in history one of the two antagonistic powers taking advantage of the other's temporary weakness, conquered and held on to land deep inside the latter's territory. Thus the two civilisations not only coexisted for a long time, they violently interacted too on several occasions.

2.2 Crete (Minoan)

Another great civilisation thrived on the island of Crete and other islands of the Aegean sea and passed through the Bronze age before 3000 BC. Records of this Minoan civilisation divided into early, middle and late periods exist from 2800 to about 1000 BC. Their script was deciphered in the middle of this century. Minoans, particularly the people on the island of Crete, had close cultural and trading contacts with Egypt even before 1400 BC and were noted for their luxurious life style and the great sophistication of their garments, specially the ladies' dresses. The city of Cnossos on Crete was destroyed after 1400 BC, perhaps due to some natural disaster but the remnant of this civilisation on the other islands was literally wiped out by the later Indo-Aryan Greeks.

2.3 Early Indian

Let me now briefly narrate our own ancient history most of which must be well-known to the readers. Our Mohenjodaro-Harappa civilisation extended over a large area in the present Punjab, Sindh and up to the delta-region of the river Narmada with an excellent port for maritime trade located at Barygazza (Bhrigukachchha). By the most conservative estimate these archaeological relics are dated back to about 2600 BC, if not earlier. the level of culture determined by potteries and other artefacts from various Harappan sites bear a close resemblance to the level of those found in the excavations at Baluchistan, North-West Frontier Province, and beyond the Hindukush mountains in Persia and Iraq. This points to a continuity and parallelism in the ancient civilisations spread over a vast region from the Indus basin and the land of five rivers in the east to Babylonia on the west. According to some records the Harappans had trade contacts with Babylon, not only along land routes across the mountain passes, but along the coastal waters too, in small vessels fitted with sails and oars that could navigate Sindh between Mohenjodaro and the sea. Every Indian high school student has read about Harappa-Mohenjodaro cities and I need not recount these well-known details. It stands to reason that the sophisticated urban culture developed by these people did not arise overnight; their history must have evolved over at least 1000 - 1500 years farther back in antiquity from a stage of small rural communities before attaining to the level found in the relics of these citadel towns. This strongly suggests that the Harappa civilisation is also as old as the Egyptian / Sumerian civilisations.

At the present time there is an expert group who tend to establish on the basis of their research that the Aryans had been originally inhabiting this land and spread to the middle-east and other places from here. This contradicts the more generally held earlier historical verdicts on their migration in waves from regions in or around southern Russia at different times, transformations in their nomadic way of living over centuries after coming into contact with the ancient civilisations of the middle-east and their final settlement in their lands of adoption in agragrian communities living on agriculture and animal husbandry. According to this traditional view of the history of the Aryans, one branch of them came to Iran from the north sometime during 2000-1600 BC, and following some differences of opinion on their deities between two groups, one group migrated to India around 1600 BC. As a novice in History, I do not want to go into the merits of the two alternative expert opinions. I shall only cite one reference, 'The history and Culture of the Indian People, Vol. 1, the Vedic Age', ed. R.C.Majumdar, published by Bharatiya Vidya Bhavan where, in different sections of one of the contributions, two experts have discussed the opposing views. After reading these articles, the preface to the whole book by the erudite editor, and the foreword by K. M. Munshi, I have formed a general impression that by far the majority of expert opinion is still in favour of the traditional version.

Granting then that the Aryans came to India from Iran we have to recount the traditional history. In their characteristic habit and style these virile people, equipped

with horse driven chariots and weapons of iron, destroyed the citadel towns in the land of the rivers Sindhu and Saraswati where they first settled down. The vanquished people who escaped the onslaughts fled to safer destinations farther south and the victors, having no taste for and experience of city dwelling, allowed the abandoned town to be vandalised, thereby further speeding up their ruination. However, I must stress that these Aryans, who came to India, were long past their nomadic habits, had already taken to a settled life and assimilated many traits of the civilisation and culture prevalent in the middle-east during their long stay in Persia. Soon the new immigrants created a life of abundance and prosperity for themselves from the products of the fertile land they had settled on and the domestic cattle they raised. The refreshing vitality of their outlook to life and the world permeated their social, religious and political activities.

The most valuable legacy they have left for us are the Vedas the first of which, Rigveda Sanghitā, is dated about 1500 BC by the most conservative estimate. It is a collection of hymns (Sukta in Sanskrit) composed by members of several Brahmin families in Sanskrit of the time with a well-laid metrical structure (Chhanda) of the Shlokas (Shloka = rik) of each hymn. Next came the Sāma nad Yajurveda, perhaps within a couple of centuries and the fourth, the Atharvaveda, all experts believe, was composed at a much later date. The Samaveda is, in fact, a collection of hymns selected from Rigveda, and meant to be sung during sacrificial rites. Each of the Vedas begins with a Sanghitā portion containing hymns addressed to various gods and goddesses, sometime to the earth, the rivers and many other entities, including one hymn in Rigveda Sanghitā addressed to even croaking frogs. There are many hymns in the Vedas that unequivocally speak of one creator - one God - of this universe but the Vedic Hindus also liked to worship the various manifested powers' bounties and magnificent beauty of that one in nature as many gods and goddesses. After the Sanghitā in each Veda came the Brāhmana in prose laying down the mantras and directions for sacrificial rites. Inserted in the Brāhmanas are well defined portions that were prescribed to be studied in āsramas of preceptors dwelling in forests and hence these portions are called Āranyaka (Aranya = forest). Finally, dispersed in the Brāhmanas or the Āranyakas, and sometimes separately at the very end of the Vedas [1] (end = Anta in Sanskrit, hence Vedānta), are laid a set of Upanishads or Vedāntas each one rich in its philosophical contents on questions and answers about our individual 'self' and its oneness with the supreme all-pervading Brahman (the monistic message of Vedānta). The Vedas were initially transmitted from memory by words of mouth by generations of teachers to their students, reciting strictly in accordance with well-laid pronounciation and accent of each syllable and word. As a result when these were properly compiled much later, some differences have arisen due to slight variations in the memorised versions available in different regions and schools. The different recensions now go by the names of the respective schools. In particular, Yajurveda has two slightly different versions called Krishna and Shukla Yajurveda.

[1] Isha upanishad is an exception; it occurs in the Sanghitā portion of Shukla Yajurveda.

The Vedas contain a lot of historical, geographical and other secular informations that make them a valuable source of our present-day knowledge about India prior to, say, 1000 BC. However, one has to remember that some of the later Upanishads were composed and inlaid into the respective Vedas at a later date.

At the risk of some dilatoriness, I shall also outline the Vedāngas (1000-500 BC) and the six systems of Indian philosophy (the Shaddarshana) which were propounded over a few centuries overlapping, it is believed, with the Vedanga period and definitely ending well ahead of the beginning of the Christian era. These works too constitute an important cultural heritage of India. In addition to the rich philosophical contents of the Upanishads, the Vedas contain a sprinkling of the astronomical and mathematical knowledge of the Vedic Aryans and their secular knowledge of some other branches of natural philosophy (i.e. physical sciences of the time). The Atharvaveda contains a great deal on diseases and ailments and their prescribed cure but most of the material does not qualify as proper medicinal treatments. The Vedangas have six subdivisions - Kalpa, Shikshā, Vyākaran, Chhanda, Nirukta and Jyothsh (all Sanskrit words). As the names suggest most of these are on secular subjects - Nirukta is a compilation of rules of Vedic grammar and pronunciation and Jyotish, in particular, relates to Astronomy and Astrology. Kalpa is mostly devoted to sacrificial rites for ordinary householders and religious rites for them on various family occasions like birth, marriage, death etc. But a part of it also deals with Dharmashāstra, i.e. the duties and observances of an ideal member of the society including the solemn duties of a king towards his subjects. These are to be distinguished from the later Dharma Sanghitās of which Manu Sanghitā is the most famous and has suffered many indignities in the hands of so-called 'progressives' in modern times.

On the six systems of Indian philosophy, Vaisheshika propounded by Kanāda stresses an atomistic origin of all matter. Nyāya of Gautama extends the Vaisheshika list of the basic ingredients of creation and surprisingly, both include space and time in their respective list. Nyāya particularly develops a comprehensive system of logic, its application to arguments and analysis to a highly sophisticated form. Shankhya ascribes a duality to creation comprising Prakriti (= the material world) and Purusha (= pure consciousness). It is very close to present-day scientific concepts about inanimate matter and conscious life form. Patanjali's Yogadarshana prescribes yoga practices for the ultimate realisation of the unity of 'self' and 'Brahman'. the other two systems are Jaimini's Purva Mimāngsā and Vyāsa's (there were many Vyāsas and this one is one of the last few) Uttara Mimāngsā which expounds the monism of Vedanta.

For readers belonging to the field of sciences, I would also like to mention the Shulvasutras by several authors, Baudhayana belonging to about 600 BC being the most famous of them. These sutras reveal the knowledge of geometry and mensuration as well as the skill of solving indeterminate equations present at the time. They prescribed the rules of laying yajnavedis (sacrificial platform) of various shapes with standard bricks of several measures. The so-called Pythagorus's theorem was used with ease in these sutras much earlier than the known historical time of the

famous Greek who was credited by his own countrymen of later generations (200-300 BC) for having discovered this theorem in 540 BC ! I also mention the Ayurvedas, which are treated by some as subsidiary vedas (upavedas) and by others as an additional Vedānga. These treatises contain ancient Indian Medical Sciences - Physiology, Anatomy, Medicine and Surgery - to the extent the medical experts knew and practised. According to present day expert opinion some of the medicines originated in the Mohenjodaro-Harappa civilisation; there was a continuity in the development through the Vedic and Vedānga periods and most of the systematic compilations were done subsequent to the Vedānga period. The famous Charaka and Susruta (on surgery) Sanghitās are such recenssions of all the old works available to the two authors together with a lot of material based on their own research and medical / surgical experience. The presently available version of the two are redactions by other authors in the Christian era.

2.4 Later Egypt/Middle East/Persia

I have deliberately devoted a disproportionately large space to the very ancient part of Indian History much more than the measured space given to the other old civilisations. I need not apologise for this bias that I could not help as an Indian.However, I have added a table (Table 1) on the others listing the kingdoms in different columns and the events horizontally. The table may be closely perused at this point.

Let me now quickly deal with the Indo-Aryans that stayed on in Persia after a branch of their brethren left for India. Persia was, in those ancient times, the name of the high plateau land to the east of Sumeria, and further north from Persia the land was called Mede. Both these regions were settled in by kindred people who are often loosely referred to as Persians although, strictly speaking, the northern people are to be called Medes, as has been done by careful authors. Both these Aryan clans distinguished themselves as regional powers to reckon with at the time the semitic Chaldeans were establishing their authority in Babylon. The three joined their forces together and destroyed the Assyrian power at Nineveh in 612 BC. The kingdom of Mede at this time extended upto the Indian mountains in the east with their capital at Ecbatana. Cyrus conquered Lydia (Asia Minor), Mede and Babylon roughly between 560 and 540 BC and established the first Aryan Empire' that of Persia. He set the Israelites free and sent them back to their land (538 BC). His son Cambyses became king in 529 BC and brought Egypt under Persian rule in 525 BC. Darius I became king in 522 BC and extended the Persian empire upto the land of five rivers in India, on the east, and over the whole of Western Asia upto the Mediterranean (inclusive of Egypt as well with capital cities at Susa and Persepolis. When he subjugated Asia Minor, he was face to face with challenge from another upcoming, self-confident and proud nation of Indo-Aryans who lost their colonies on the Mediterranean coast at a result of Darius' conquest.

Table 1. D stands for dynasty; number in parantheses denotes year BC

Egypt	Other States	Sumer/Babylon/Assyria/ Mede/Persia
1st D (3400) Old kingdom at Memphis 3rd-5th D (2980-2400) 4th D - the pyramid builders (2900 - 2750) 6th-10th D period of decadence Middle kingdom at Thebes 11th-12th D (2160-1788) Hyksos (shepherd kings) from Asia Defeated Egypt using horse-dirven chariots, unknown to Egyptians at that time. Ruled Egypt for about a century . New Empire at Thebes (No-Amun) 18th-19th D (1580-1150) - Egypt reached pinnacle of power, subjugated a large part of Asia. Rameses II (19th D) - perhaps the persecutor of Moses and his fellow jews. Temple of Amun at Karnak, extensive building activities - temples obelisks, underground tunnels leading to Pharaos' burial chambers. Rise of Amun priests as a powerful class. Period of decadence Rule by Lybians, 21st-24th D (1090-712) King Shishak, 22nd D (945-745). Capital at Bubastis in Nile delta. Plundered Jerusalem. 24th D: disintrigation of empire under small local rulers. 25th D (712-663) D established by Nubean Lord, Piankhi, who defeated the small rulers one by one. Assyrian attack and withdrawal due to outbreak of plague. Assyrian conquest of Egypt (670) and withdrawal (668). 26th D: Egypt regained freedom (663), established capital at Sais in the delta. Saitic period (663-525). Greek mercenaries admitted into Egyptian army. Resurgence of power under Necho II. Conquered Syria, Judea (608) but was defeated by Chaldeans when his army reached the Euphrates.	Early,middle,late Minoan (2800 - 1400) Phoenecians, the first sea-going people, began trading in Aegean sea and Mediterranean since the time of Hammurabi (~ 2000) [see next column to the right] Hittite power in Asia Minor (1700-1200) Phoenician city states Tyre,Sidon), Syria under Egyptian Suzerainty Cnossos of Crete destroyed after (1400) Exodus of Jews from Egypt (1232) They roam in Sinai desert for many years on their way to coveted land. Phoenicians reach their peak (1200 - 800) Establish colonies in North Africa, Spain (Carthage most famous) Israel: short period of prosperity under David (1010-970) and Solomon (970-933). Division into north and south (called Judah or Judea). Ravaged by Egyptian Pharao Shishak after Solomon's death.	Sargon I started Akkadian Empire (2750) Hammurabi (2130-2087), first Babylonian D, empire spread to Mediterranean coast. He gave a uniform set of laws for all subjects. Bel Marduk-the Babylon god. Priests used to collect Astronomical data from top of temple buildings called Ziggurats. Indo-Aryans arrive and settle down in Mede/Persia (2000-1600) Series of Babylonian D's (2087-1250) Rise of Assyrians in Nineveh (1380-) Zenith of Assyrian power (900 - 668) Tiglath Pileser III conquered Babylon (745) and established Assyrian Empire. Sennacherib conquered Judea, attacked Egypt, withdrew due to an outbreak of plague. Assurbanipal (also called Esharhaddon) conqured Egypt (670) and died in (668). His library was the first and foremost in ancient times. Decay and end of empire (606). Chaldean Empire at Babylon (605-539) Chaldeans: inhabitants of Tigris-Euphrates Valley. Chaldean Nebuchadnezzar (605-562) came to power at Babylon. Destroyed Nineveh (606) jointly with Mede and Persia. Defeated Pharao Necho II. Conquered Israel and brought the Jews as captives to Babylon (597). Babylon flourished as a great centre for trade, commerce and learning. Last king Nabonidus was very generous

Table 1. Contd...

Egypt	Other States	Sumer/Babylon/Assyria/Mede/Persia
Persian conquest of Egypt (525) Egypt remains under Persian rule (525-332) Greek Occupation (332) Greek rule from Alexandria (332-31) Roman occupation of Egypt (~ 31)	Jews deported and taken as captives to Babylon (597, 586). Restored in (538). Their prophets wrote the first testament during captivity.	to gods of other cities as well. Priests of Bel Marduk conspired with Persians and opened the gate of the city one night to Persian army. End of Nabonidus and his son Belshazzar (539). Persian Empire Cyrus established the first Persian empire at Babylon (539) and set the Israelites free (538). Cambyses conquered Egypt (525). Darius I extends empire. War began with the Greeks. Alexander devastated the empire, occupied Babylon, Susa, Persepolis and burned down the palace of Darius III.

2.5 Greeks

These Indo-Aryans had first come over to ancient Greece around 1200 BC as a horde of nomadic marauders from the north and very soon vanquished the Mycenean population there by superior military might. They settled down in cities in the valleys between mountains and, with time, each city became a city state administered by the powerful elite. They are the celebrated Hellenic Greeks of history. At the initial stage they were nearly barbaric and had no written script of their own. Over a few centuries they mastered maritime skill and with their newly floated fleet established their colonies on the Aegean and Mediterranean islands and also at a few places (Troy, Mycenae etc.) along the coast in Asia Minor. The evicted people fled to various places - some (the Etruscans) to Italy and a large number (called the 'sea people' in history) reached the Egyptian shores with their boats for shelter. They were beaten both on the land and sea by the Pharao's men and they eventually established themselves in the southern part of Phoenicia, called Canaan. They are known in history as the Philistines and their new found homeland as Philistia. For a time they were involved in constant skirmishes with the Jews living to their east in the mountain valleys of Israel.

The Phoenicians, who were the first sea-fearing people in history, since the days of the Babylonian Emperor Hammurabi (about 2000 BC), passed through a glorious period of maritime trade (1200 - 800 BC) in the Aegean and Mediterranean, and established several colonies on the southern coast of Africa (Carthage being most renowned), and in Spain. the new Greek hegemony on the seas gradually stifled the prosperous Phoenician trade and commerce after about 800 BC. However, Carthage was still very powerful.

The end result of the colonialisation brought the Greeks material prosperity and, what is more important, the process of colonisation exposed them to the old Minoan,

Mycaennean and the Asian civilisations. They realised soon what was lacking in their social culture, despite the virility and military power as a nation. Of the latter they were rightfully proud and self-assured. Personal freedom was fostered by their form of governance (republic of the elite citizens) at this phase of their national development. By 500 BC they produced a class of gifted people endowed with refreshingly independent intellectual qualities. These vanguards of the Hellenic civilisation have left a rich legacy in every branch of human knowledge and intellectual activity - literature, drama, philosophy, politics and rudiments of science.

I have now brought all these interacting and overlapping civilisations to the vicinity of 500 BC. In India this was the period of Buddhism and Jainism. The situation in the middle-east, already described and displayed in Table 1 was poised at this point in history for an inevitable showdown between the upcoming Greeks and the entrenched Persian Empire. After several battles with ups and downs the Greeks came out victorious. First, Darius I conquered the Aegean islands one by one, landed a huge army at Marathon but was defeated by the Athenians. Second, after Darius's death his son Xerxes crossed the sea by a bridge of boats at Dardanelles and attacked Greece on land along the coast. At a narrow mountain in Thermopylae Spartans (the Greeks of the city state of Sparta) inflicted heavy losses on the Persian army but were totally annihilated in the end. The Persians sacked and burned Athens. Third, the Greek fleet routed the Persian fleet in the bay of Salami. Fourth, the retreating Persian army was defeated in the battle of Platea (479 BC). Fifth, the remnant of the Persian fleet was annihilated at Mycale near Asia Minor.

The Greeks, now very confident of their martial invincibility went through a phase of great national fervour and were gradually building up a tempo towards a last triumphant showdown by taking the war to the territory of the Persians. In between they passed through an unfortunate civil war for supremacy amongst the different city states, to which the kingdom of Macedonia of a kindred people, was also drawn in. Finally, Philip - the King of Macedonia subjugated the others (338 BC) and the newly formed Greco-Macedonian Confederacy appointed him captain general for the expedition to the Persian empire. He was soon assassinated and it befell on his son and heir to the throne, young Alexander, to embark on his father's task starting 334 BC - a task he loved heartily.

I shall give a summary of the expedition of which the Indian part must be well-known to the readers: (1) Alexander moved down the Phoenician coastline, occupied Tyre and Sidon, defeated Darius III on the way; (2) defeated the Persian rulers of Egypt which passed under Greek rule (332 BC); (3) marched towards Babylon, smashed the regrouped Persian army at Arbala near Nineveh; Darius III fled towards east and died soon after; (4) occupied Babylon, Susa, Persepolis and in a drunken orgy burned down Darius' palace; (5) marched towards Turkistan across the Oxus-Jaxartes valley, met with a military disaster at Samarkhand, retreated and finally entered India; (6) occupied Gandhara and a part of Punjab and Sindh and returned to Susa (324 BC); (7) died the next year; (8) Asian and Indian empire of Alexander passed on to Seleucus, one of his generals; (9) the Seleucid rulers at Babylon (wore

the Persian tiara) and the Ptolemies in Alexandria (called themselves Pharaos) became integrated with the local society - a cross fertilisation of the two cultures took place as time went on; (10) in India too a similar cultural assimilation occurred and the resultant nature of exchange of ideas in philosophy, art, science, mathematics etc. is still a matter of historical research, i.e. who received what from whom is still a difficult score to settle.

2.6 India (500 BC - Gupta era)

This is the right place for me to bridge the gap I have left in my Indian story between the Vedic-Vedānga era and the time of Alexander's invasion. This material is not very well-known to our young students through their curriculum. The Indian polity in the early Vedic days was very much fragmented into small units of Aryan clans and non-Aryan tribes. Rigveda talks of a war of ten such kings, with the details of their locations against the powerful Tritsu king Sudāsa. Out of these multitude of kingdoms gradually Kuru and Pānchāla came out as the most powerful ones. During the Buddha's time Kuru-Pānchāla had dwindled in importance and in their place Magadha, Kosala, Avanti, Batsa and the Vajji federation - the latter a group of republics with Videha and Lichchhavi the dominant members - had come to the forefront. Kosala was the largest of them and had already subjugated Kashi and held suzerainty over several small republics - Shakya, Kolya and Malla. Another important place at this time in history was the kingdom of Gāndhāra between the river Vitastā and the Hindukush mountains with its capital at Taxilā. Its importance derived from a University at Taxila where, besides the Vedas and philosophy, a large number of secular subjects like politics, economics, administration, medicine and martial arts were offered on the curriculum. All the princes of the north India used to receive their training in this university. Besides them, a large number of meritorious commoner students also studied here - some paying their tuition and the very poor being supported by grants and part-time work in the preceptor's house. Ajātasatru, son of Bimbisāra, was a student of this university. He occupied the throne of Magadha after killing his father and then conquered the Vajjis in a protracted war over about 12 years ending around 470 BC. He had shifted his capital from Rājagriha to a new garrison city built by him at Pātaliputra (near present Patna). After the death of the Kosala king Prasenājit (also a Taxilā student in his youth) - Ajātasatru's maternal uncle and father-in-law - the next king, Prasenājit's son Bidudābha, perished with a large army after a very short reign in a flash flood of the river Achirāvati. Thus Kosala also came to Ajātasatru's possession. This was the beginning of annexation and formation of a large empire in India. After the Bimbisāra dynasty ended in Pātaliputra, the new dynasty of the Nanda kings (also called Gangaridai kings) gradually extended the Magadhan empire upto Punjab. It is said that Alexander decided to get back to Persia from the banks of Vitastā because his mercenary army, recruited at various places during his long expedition, refused to proceed farther east after having heard about the powerful Gangaridai king and his numerous elephant brigades.

After Alexander's departure an ambitious young man, Chandragupta - perhaps a student at Taxila - advised by his preceptor Kautilya (also known as Chanakya) belonging to the same city and famous for his works on Arthasastra, recruited and trained an army from the tough tribals who had earlier given a courageous resistance to Alexander. He swiftly attacked the then lethargic and comfort-loving Greek administrators and their Indian subordinates and reoccupied most of Alexander's Indian possessions. Originally hailing from the clan of Mauryas in north Bihar under the sovereignty of Magadha, he was determined to defeat the Nandas. By a carefully planned strategy he proceeded slowly from the north-west, fortified each region he gained and took several years to make the decisive thrust on Pātaliputra. Finally, he became the ruler of a vast empire. When Seleucus invaded (303 BC) from the north-west to recover his lost Seleucid territory, Chandragupta defeated him and forced him to sign a treaty by which the Greek surrendered Kabul, Kandahar, Hirat and Baluchistan to the Maurya. The subsequent story of Ashok, Chandragupta's grandson, is well known to Indians. He became a Buddhist, consolidated and ruled his vast empire in the name of Dharma (264 - 227 BC). H. G. Wells has described him as the greatest and most benevolent emperor in the history of the world of all times. We have read about his missionary work for the spread of Buddhism in India, Sri Lanka and also beyond the Hindukush.

After the decline of the Maurya empire there was a period of confusion over several centuries when foreign invaders came one after another and settled themselves in their new possessions. They are the Baktrians (Bāhlika in Indian languages), Scythians (Saka), Parthians (Pahlava) and Kushānas - the dominant branch of the Yue Che's who originally migrated from boundaries of China to the land between the rivers Oxus and Jaxartes (Amu daria and Shir daria). Kanishka, ruling in the beginning of the 2nd century AD, was the most famous Kushāna king who, like Ashok, adopted Buddhism and propagated it all over his large empire extending upto the Chinese border along Central Asia with Khashgar, Khotan and Yarkhand also under his realm. The Kushāna dynasty ended around the middle of the third century AD and the troublesome Shaka satraps once again became dominant. They were finally subdued and the country was unified again under the leadership of Magadha. With a humble beginning the Gupta dynasty came to the throne of Pataliputra and very soon rose to the pinnacle during the reign of Samudragupta and his son Vikramāditya. This dynasty ruled from 320 AD to 540 AD during which the unified empire passed through a golden age in peace, prosperity, works of art, sculpture, astronomy, mathematics and other branches of science. Our Siddhānta Jyotish thrived during this era and hence, as proposed earlier, my account of Indian history will be closed at this point.

2.7 Decline of the Greeks

Let me now get back to the middle-east where I left it. Alexander's great respect for Aristotle - his private tutor as a boy - was shared by the first Greek Pharao, Ptolemy I. He created a very rich trust fund to support a museum and a library in Alexandria

which, under his patronage, soon became a great centre for research and learning. The museum attracted many scholars who lived and worked there with stipendary emoluments. Some of the well-known names are: (1) Euclid, the famous geometer, whose works have survived to the present day as a first course in high-school geometry; (2) Archimedes, the renowned scientist specialised in mechanics and hydrostatics, who hailed from Syracuse in Sicily; (3) Eratosthenes from mainland Greece who first estimated the radius of the earth to an accuracy of 50 miles; (4) Claudius Ptolemy ($\sim$ 150 AD) who worked on astronomy and related mathematics and published his famous book Syntaxis (called Almagest in later Arabic translation) on his astronomical observations, instrumentation and calculational methods. He wrote a book on astrology as well. The library acquired nearly half a million books and manuscripts, all handwritten on the famous papyrus leaves of Egypt. Translations of standard works available in other languages and production in bulk of handwritten books for sale used to constitute a major part of the activities of the library. The first two Ptolemies, as Pharaos, were genuinely interested in intellectual pursuits. After them the Greek rulers of Egypt gradually got into the old Egyptian mould when the cult of temples and priests once again prevailed in civil life. The two great institutions gradually decayed after flourishing for three to four centuries.

After the Graeco-Macedonian Confederacy encroached upon the free civil and political life of the city states, the creative activity of the mainland Greeks had been dwindling all the time and intellectual activities got restricted into preservation and routine perusal of the Platonic and Aristotelian works without any applications of in-depth analysis. In the middle-east the Seleucid empire, established after Alexander's death, shrank considerably having lost all its possessions to the east of Euphrates. Babylon lost its importance and the capital of the empire shifted to Antioch in Syria. Asia Minor came to the fore under the Attalid kings based in their capital at Pergamum. The Macedonian empire controlled, besides Macedon, a large part of Greece and whole of Thrace on way to Asia. The city states like Athens and Sparta were languishing into decadence but still maintained an independent administration outside the jurisdiction of Macedon monarchy. the Achean League and Aetolian League were playing a major political role in mainland Greece. Independent republican city states that were still prosperous and thriving with the Hellenic intellectual vigour belonged to what was earlier called Magna Graecia at the zenith of Greek ascendancy. Syracuse in eastern Sicily (home of Archimedes) and the small island of Rhodes (with an excellent astronomical observatory, where the famous astronomer Hipparchus worked) belong to this category. Magna Graecia also comprised a few Greek city states established in the southern extreme of Italy (the 'toe' and 'heel' on the map), Tarantum and Neapolis being quite well-known of them. In the field of art, sculpture and architecture Alexandria, Antioch, Pargamum and Rhodes thrived for a long time and took the Hellenic traditions to spectacular heights. In spite of the fragmentation and shrinkage of the great empire of Alexander, the Hellenic culture maintained its inherent strength and still prevailed over a large part of the civilised world. However, as already mentioned, its fountain head of creativity in philosophy and science - closely

linked with the basic liberty of the human mind fostered by a small republican city state - was fast drying up under the huge political and military superstructure of a far flung empire.

2.8 Carthage

Carthage, a great semitic trading city on the north coast of Africa (near present day Tunis) facing the island of Sicily, was flourishing at this time to the west of the Greek possessions. The Phoenicians from the cities of Tyre and Sidon established this city around 800 BC and spread their maritime trade up to the south of Spain where they controlled very rich silver and copper mines. Over the next two centuries the Greeks had evicted them from their trade in the Aegean and Eastern Mediterranean and finally they lost their freedom in the homeland cities of Levant under Alexander's invasion ($\sim$ 334 BC). However, Carthage prospered all this time without any interference from the Greeks. She had a fleet of large naval vessels (galleys fitted with 5 banks of oars) and equally large number of trading vessels which gave them an unchallenged mastery of the Western Mediterranean, of their possessions in Spain, and over the trade with thriving ports established all along the north and western coast of Africa upto the mouth of the river Congo. They held several colonies on the west coast of Sicily (the eastern colonies of Sicily being under the Greeks) and whole of the islands of Corsica and Sardinia. The hinterland in Africa to the south of Carthage was very fertile and studded with vast rich estates. The neighbouring African kingdom of Numidia, although not friendly, had accepted the Carthaginian supremacy.

2.9 Rome

The Hellenic and the semitic world depicted here started receiving mild tremors from Rome, the newly emergent power in the west, between five and six decades after Alexander's death. By and by it became a colossus and swallowed all the Greek and semitic possessions; subjugated Gaul ($\sim$ present day France) and the land of various Teutonic tribes in the Rhine valley stretching upto the Danube in the north and pillaged the Black Forest area of present day Germany even beyond that river; on the extreme west, crossed the channel and conquered parts of Britain.

Founded in 753 BC on the river Tiber in Italy, the city of Rome had an humble beginning; its Latin speaking population drove away the Etruscan rulers about 500 BC and established a republic administered by a set of magistracy, appointed and controlled by a powerful Senate of patricians - men belonging to the rich landed aristocracy. In a couple of centuries Rome was in possession ($\sim$ 350 BC) of the fertile lands of Campania and the manufacturing city of Capua; had subdued the other Latin speaking cities (338 BC), several non-Latin tribes of the Appenines, the Etruscans of the city of Veii (396 BC) near Rome, the northern Etruscans, Umbrians, Sabines, culminating with the Samnites (326 - 293 BC), a virile mountain tribe who remained unreconciled even after their final defeat (293 BC). Earlier, in 390 BC, she was brought

to the verge of ruins by the Gauls from the north of the Appenines who sacked Rome and left only after collecting a huge ransom. She showed enough resilience and got over the ravages of the barbaric invasion by 350 BC. Her first armed confrontation with the Greeks took place in 280 - 275 BC when Tarentum, a neighbouring Greek colony of southern Italy, invited Pyrrhus of Epirus (present Albania) to bring an end to the Roman ascendancy. One of several small-time Greek generals floating around Macedon after Alexander's death, Pyrrhus himself entertained the ambition of being the master of Magna Graecia. He fought the Romans and won several battles with gradually diminishing margins. In the meantime, Carthage, worried by a Greek adventurism so near home, moved some naval vessels cutting off his supply line across the sea; coincidentally, the Gauls, instead of marauding the south - their usual haunt - marched at this particular time towards east, that is, Macedon and Pyrrhus' own homeland. Pressed by these adverse circumstances, and a fresh thrust on the battlefield by the Romans, he withdrew his forces from Italy leaving Rome to take over all the Greek colonies there. Rome thus became (275 BC) the master of Italy from the Appenines to the Mediterranean coast - part of it under her direct possession and administration and the rest through her allies, the Latins and non-Latins each bound with Rome by treaties of interlocking loyalty.

The second phase of Rome's expansion took her beyond the borders of Italy. In three successive wars (263 - 241, 218 - 202, 146 - 143 BC) she totally annihilated Carthage and occupied the latter's possessions in Sicily, the islands of Corsica and Sardinia; took undisputed naval control of the western Mediterranean; acquired sovereignty over Spain up to the river Ebro in the north and finally over the African hinterland of the great trading city. In addition she extorted huge war indemnities at the conclusion of the first as well as the second war, took a large number of prisoners to work as slaves on large farms and ranches back on her home territory. The third war was fought with the flimsiest of excuses when Carthage was already crippled as a trading and naval power and was confined, more or less, to her city limits. After three years of siege, the Romans entered the city, killed a quarter of a million people in street fighting and took fifty thousand as prisoners to add to their domestic slave market. The city was burnt down, the land ploughed and sprinkled with salt - an extraordinary act of barbarity for which Rome had earlier (146 BC) established a precedent while sacking Corinth, a Greek city, to which I shall come soon. Any reference to these Punic wars remains incomplete without the mention of a single name, that of Hannibal - a great Carthaginian general - who carried the second Punic war on to Rome's own territory and fought for fifteen years after having bravely crossed the Alps and the Appenines with his army of forty thousand men under the severest weather conditions. On one - after - another battlefields he routed Roman legions overwhelmingly superior to his army in number. Towards the end of the second war he was recalled to Carthage when a young Roman general, Scipio, landed an army on the African soil after achieving a commendable success against the Carthaginian forces in Spain. In the battle of Zama (202 BC) the young general defeated Hannibal who fled to Syria and later, pressed by the Romans in Asia, took poison and died.

In the territories occupied abroad, Rome created Roman provinces and appointed Roman governors to administer each of them. In between the first two Punic wars she had first taken the Greek colonies of Sicily as allies and later integrated them into a single province of Sicily under one governor. That was the end of Syracuse, the city of scientist Archimedes, as a bastion of Hellenic culture. In Italy too Roman expansion took place beyond the Appenines in Cisalpine Gaul where Rome established a set of well planned colonies in the Lombard plains as a line of defence. Rome also took control of the Adriatic coast, and established a naval base at Epirus, outside Italy, to remove the menance of pirates.

Rome came into contact with the Hellenic kingdoms in 200 BC immediately after the second Punic war when she invaded Macedon at the invitation of the Aetolian league. The league disliked Macedonian enroachment upon Greek sovereignty and Rome was already displeased with King Philip V of Macedon for having entered into diplomatic negotiations with Hannibal when the latter had been marauding southern Italy in the second Punic war. Philip was convincingly defeated (197 BC) but the Roman general, ignoring the opposition of his Greek allies permitted Philip to continue ruling Macedonia. Of course, Philip was forced to withdraw from Greece and he promised not to undertake any military operation without Rome's consent.

Antiochus III, the ruler of the Seleucid kingdom of Syria, had extended his sway in the east between 212 and 206 BC and, with the humbling of Philip, he started expanding towards Asia Minor and Thrace. The Aetolian Leauge, dissatisfied with Rome's liberal dealing with Philip, urged Antiochus to move into Greece. Pergamun and Rhodes sought Roman intervention. Rome was particularly peeved because Antiochus had Hannibal as his advisor. Romans pushed Antiochus back into Asia and defeated him decisively in the battle of Magnesia (189 BC). By the ensuing peace treaty he was confined to his own kingdom, had to surrender his navy to the relief of Rhodes and paid a huge indemnity to Rome. Hannibal evaded capture by committing suicide as was mentioned earlier. Rome thus established her military supremacy over all other neighbouring contemporary powers and had held the right to dictate terms at her will to them. She still did not touch Egypt, enigmatically, because the latter was too weak to harm Rome's interests in any conceivable way.

Under Philip V and later his son Perseus, Macedon made a grand recovery by using her own mineral wealth and made diplomatic overtures towards the Greeks who were already dissatisfied with the high handiness of the Romans. Alramed by the trend, and urged by Pergamum, Rome again went into war against Macedon in 171 BC. In the battle of Pydna (168 BC) the Roman legions convincingly proved their superiority over the Greek phalanx. Perseus was taken as prisoner to Rome where he died in captivity. Macedonia was split into four republics and her lucrative mining operations were closed down. Internal revolt continued for two decades and finally Rome declared (148 BC) Macedon, Epirus and Illyricum (present Yugoslovia) as a Roman province of Macedonia administered by a Roman governor. In 146 BC, the Aechean Leauge incurred Rome's displeasure. Invited by Sparta, Rome gave a lesson in brutal reprisal to the erring Greeks. The city of Corinth, as mentioned earlier, was totally destroyed;

its valuable works of arts and treasures were looted; the women and children were sold to slavery - a precursor of the tragic fate of Carthage three years later ! The Greek cities were brought under the governor of Macedonia. Meanwhile, Rhodes tasted the humiliation of continuing to be a Roman ally. Her maritime trade and prosperity dwindled because of her inadequate power to keep piracy in check. Rome had opened a free port at Delos which became more attractive to traders because of thriving slave trade there. Importance of Rhodes as a trading post gradually dwindled, and with it drained away the vital force of Hellenic culture of the island. King Attalus III of Pergamum, having endured similar humiliation, had realised the futility of enjoying so-called independence under Roman tutelage. He bequeathed his kingdom to Rome at the time of his death (133 BC) and it became the first Roman province in Asia (129 BC).

Antiochus IV, successor to Antiochus III, of Syria was reduced to a puppet by the Roman envoy in his court. The Seleucid power rapidly declined and after 160 BC, there arose several small kingdoms - Bithynia, Pontus (also called Punt) and Armenia to the east of Asia Minor - which along with the mighty kingdom of Parthia to the east of Euphrates were very soon to be a major source of trouble to Rome.

After the first Roman province of Asia was established at Pergamum, Roman economic exploitation had become rampant both by direct collection of taxes by Roman contractors (called equities at home) and through the money lending trade which had spread even to friendly neighbouring kingdoms. The entire trade and commerce in the Aegean had passed to the control of the Romans. Roman financial agents had spread their tentacles even in the Greek cities. The entire region was soon seething with discontent against the Romans. King Mithridates VI of Pontus, in this general background, had been extending his sway over the Crimea and the land to the north of the Black Sea. His kingdom on the southern shore of Black Sea flourished with grains and fishing trade based on the natural resources of those newly acquired territories and with a ship building trade of her own dependent on the finest quality pine wood Pontic forests were richly endowed with. He defeated the Roman governor on the Asiatic province, took control of several Aegean trading posts and advanced as far as Athens. Rome lost her huge Asiatic revenue and private earnings through money lending business. She was thus faced with a great financial squeeze at home and the Roman Senate acted urgently by sending Sulla, the Consul of 88BC, to conduct the war against the Pontic army. There was a tussle with the democrats of the Popular Assembly who sent another general with the same mandate. To cut the long story short, ultimately Mithridates was defeated and at the time of the peace treaty Sulla took the credit by posing as the General of the combined army. Mithridates gave up all his conquests and paid a huge indemnity. The local rulers had to agree to pay Rome in advance the lump-sum tax for every five-year period. In addition to this huge burden of taxes, the people suffered also from the loot and plunder by the victorious Roman soldiers. Sulla came back to Rome a sworn enemy of the democrats and the Popular Assembly. Senate appointed him a dictator with the task of giving a new constitution. He obliged by abolishing the Censor's post so that no check remains

on the membership of the Senate; he made new senate membership contingent upon already holding a magistracy and at the same time made the tribunes ineligible of accepting any new office; the Popular Assembly was restricted to dealing with matters referred to it by the Senate; the grain dole for the urban poor was stopped; returning army generals were required to disband their army and enter Rome as ordinary citizens. Unfortunately, Sulla himself having shown what undisputed military power could achieve in Rome, all these measures ensuring Senate's authority were soon to be flouted, as I shall presently narrate.

In 74 BC the king of Bithynia bequeathed his kingdom to Rome and it was immediately made into a Roman province. Mithridates, dissatisfied with Rome for arbitrary violations of their earlier treaty, did not like the establishment of a Roman province almost next doors. He overran Bithynia, pushed the Romans out, and seriously challenged Roman trading interests in the Aegean. Roman Senate gave the command of Bithynia, Asia Minor and Cilicia to Lucullus, who soon drove out the Pontic army from Bithynia and conquered Pontus. Mithridates fled to his son-in-law, Tigranes, the king of Armenia. Lucullus captured the magnificent new capital city of the latter near the head waters of Euphrates. His greater achievement was the reorganisation of tax collection and rationalisation of the tax burden of the citizens thereby relieving them of the undue extortion by the Roman equities. Meanwhile his own army mutinied against him because he was too strict against loot and plunder of citizens by army men. Taking advantage of this development Mithridates came back to Pontus. Roman Senate, who had earlier given a command with unprecedented power to Pompey to rid the Aegean from the pirates, further transferred (66 BC) to him the command given to Lucullus. By a swift action he destroyed the pirates, and settled the prisoners in Roman colonies established in Cilicia. Having taken over from Lucullus, he threw out Mithridates from Pontus who fled to Crimea. Pontus was added to Bithynia as a part of the Roman province. He conquered Armenia but arranged to keep Tigranes as a friend and ally so that his kingdom could act as a buffer against the more formidable Parthia. He then wished to conquer up to the extreme east (believed to be the Caspian Sea by the contemporary Romans) of the world. After fighting for some time in Transcaucacia, he returned to Asia Minor to attend to urgent administrative reorganisation. He replaced hereditary kings everywhere by his own Roman nominees. In 64 BC he evicted the Seleucid king of Syria and made it the richest Roman province in Asia. In 63 BC he captured Jerusalem and consolidated the empire up to the frontiers of Egypt.

The famous triumvirate of Pompey, Crassus and Julius Caesar took shape in 60 BC. Caesar went on his expedition to Gaul. Pompey sent his emissary to rule Spain and stayed in Rome. Crassus got the command of Syria. In his eagerness to conquer the Parthian King of the Arsacid line he rushed with his legions across the hellish Syrian desert where his army was surrounded and butchered (53 BC) by Parthian cavalry men. He was himself beheaded and his head was displayed in a dramatic performance at the Armenian court held in honour of the state guest, the 'king of kings' of Parthia. Ten thousand Roman soldiers were taken prisoners, subjected to

many indignities (including marriage with local women !) and a large number sold as slaves to the Chinese.

Caesar came back to Italy after his glorious conquests in Gaul and Britain in 49 BC. So far the established Roman practice was to disband the army and enter Rome as a private citizen. Deliberately violating this code, Caesar crossed the river Rubicon with his army. Pompey fled to Greece. Caesar carried out a swift campaign in Spain and brought Pompey's army there under his command. Replenished by an army commanded by Antony, he besieged Pompey in Greece and routed the latter's army, raised from Greece and the eastern empire, in a decisive battle near Pharsalus. Pompey took a boat to Egypt but was killed there as soon as he landed. Caesar followed him there and was caught in the dynastic skirmishes for succession between Cleopatra and her brother. Caesar's intimacy with Cleopatra and her begetting a son by him are well known stories. Caesar carried out a lightning campaign in Rome's African territory, acquired from Carthage, and established his command over it by defeating Cato. Thus when Caesar returned to Rome he was the undisputed master of the entire Roman empire in Asia, Africa and Europe. The Senate persisted in name with members of his choice packing it. The Republic was, however, dead. Caesar was appointed Dictator, and when his dictatorship was declared as a life - time assignment by the Popular Assembly, the conspiracy against him by the 'liberators' came to a head. Within six months, on the 15th March, 44 BC, he was assassinated by Brutus.

Mark Antony, Caesar's ablest marshal, was still the surviving Consul of 44 BC and wielded enough power. Octavian, Caesar's nephew and adopted son - the heir to Caesar's personal property - marched towards Rome from Illyricum with his legions. Brutus and Cassius fled to Greece wanting to raise an army in the east to counter Caeserian army in the west. With Lepidus, another trusted man of Caesar, Mark Antony and Octavian formed the Second triumvirate (40 BC). Julius Caesar's divinity was proclaimed. Antony and Octavian pursued the liberators to Greece and crushed the forces of the republic in two battles at Phillippi (42 BC). Brutus and Cassuis committed suicide. Lepidus received the command of the African Kingdom. Antony, who had demanded and got the command of Gaul in 44 BC, now opted for the command of the empire east of Illyricum; he wished to complete Caesar's mission of conquering Parthia. Octavian remained in Rome and commanded whole of Italy and the vast western empire. Sextus Pompeius, son of Pompey, was admitted into the closed circle of the triumvir and was given the command of three provinces and the Roman fleet.

Cleopatra, the Egyptian queen Pharao, had followed Caesar to Rome but he was assassinated before she reached there. She had then switched her attention to Mark Antony and gave birth to twin children after reaching Alexandria. Antony married Octavia, sister of Octavican (40 BC), thereby cementing the mutual understanding with Octavian. The marriage put a temporary stop to Cleopatra's game plans. Antony shifted to Greece with Octavia and between 39 and 37 BC reorganised and strengthened the Asian kingdoms. He repulsed a Parthian attack against Syria and then,

leaving Octavia alone, set out on his long awaited war against Parthia. Cleopatra seized the opportunity and joined him in Syria.

Between 37 and 33 BC Octavian proceeded step by step towards ascendancy over the other members of the triumvirate. He defeated Sextus and then Lepidus, thus winning the Roman fleet and the legions of the two on his side. Antony's campaigns in Parthia had failed (36 and 35 BC); he moved over to Alexandria where he was totally under Cleopatra's influence and contracted some kind of a marriage with her, not recognised in the Roman law. He bequeathed some Roman provinces and cities to Cleopatra and her children. Octavian was elected Consul in 31 BC and the Roman people gave him an oath of personal allegiance urging him to save Rome from the evil designs of Cleopatra. Octavian declared war against her and the Roman navy met the Egyptian fleet on the Adriatic near Actium (31 BC). Surprisingly, Antony boarded Cleopatra's flag ship at the very beginning of the battle and together they sailed back to Alexandria. The Egyptian fleet was left to surrender to Octavian. Octavian took his army to Egypt where the last battle was fought. Antony committed suicide. Cleopatra followed him after a few days having failed, it is said, to seduce young Octavian. Thus ended the Plolemaic rule in Egypt and with it the last vestige of the Graeco-Macedonian empire.

I have described in detail how the Roman colossus gradually took over the semitic and Graeco-Macedonian world by sheer military power. The story of Julius Caesar's conquest of Gaul and Britain has, it may be noted, been cursorily touched upon.

Desiring to establish a lasting peace, young Octavian surrendered his authority to the Senate and the people. The grateful Senate reciprocated by virtually handing over to him the power to rule the entire empire, presenting him a laurel wreath and a golden shield, and finally giving him the name of Augustus and the title of Princeps. In reality Augustus was the first of the long chain of Roman emperors to follow till 476 AD - some very good, some very mediocre, some very weak and some even abominably wretched despots. A large part of the military activities during the imperial period was directed at carrying forward the conquest of Britain which Julius Caesar had started, and on strengthening the Northern European border of the empire along the Rhine and Danube against the barbaric tribes living beyond that line. Dacia (present Romania) and Pannonia (Hungary) were conquered and made into Roman provinces. Dacia was later abandoned. In Asia there was a very short-lived supremacy over the Parthians when the Parthian capital Ctesiphon was captured by the army of Trajanus and they went as far as the head of the Persian gulf (114 - 116 AD). For most of the imperial era Romans stayed to the west of the Euphrates and their sporadic attempts to push beyond the river hardly met with any success.

An important landmark in the imperial history of Rome is the birth and spread of Christianity and the Christian Church over a wide area of the empire. Jesus of Nazareth was born in 4 BC (not in the zero-year of the Christian era !) during the reign of Augustus (31 BC - 14 AD) and was crucified by an order of Pontius Pilate in, perhaps, 30 AD at the time of the next emperor Tiberius (14 - 37 AD). His teachings gradually spread, mostly amongst the poor living in ghettoes of the cities

in Asia Minor, Syria, Greece and in Alexandria and Rome. Gradually, the message of the kingdom of heaven caught the imagination of the people in the upper strata as well and the number of followers multiplied. They were looked down with suspicion by the Roman administrators as they professed allegiance only to their one God, and not to the Roman emperor. Persecution of the Christians started at the time of emperor Nero (54 - 68 AD) who wanted to make them the scapegoats for the great fire of Rome which, many historians believe, was caused under his secret order by his own hired arsonists. St. Paul and St. Peter were executed in 64 AD. Persecutions continued at a hedious and barbaric level. During the reign of Trajan (98 - 117 AD) Christianity was declared to contravene Roman law. Terrible measures to wipe out the faith were unleased during the rules of Decius (251 AD), Velarian (257 - 260 AD) and finally Diocletian (285 - 305 AD). In the east the persecutions continued with all fury till 311 AD. The next emperor Constantine stopped the persecutions by the edict of Milan (313 AD) proclaiming freedom of worship for all and granting legal status to the Christian churches as corporate bodies. Thereafter he showed his bent towards Christianity, took part in Christian ceremonies, built the basilica of St. Peters in Rome, and founded the first Christian capital city in Greek Byzantium which was named Constantinople after him. It is well-known he was baptised on his death bed.

The Roman polity was never tired of making new constitutional experiments and creating statutory bodies and positions, as and when necessary. Initially the propelling force was exerted by the plebeians - the urban poor, small but free farmers, artisans and traders - to win a minimum of political rights from the Senate controlled exclusively by the patricians, members of the landed aristocracy. In the later history of the republic, as has been already described, the changes resulted from the struggle for supremacy between the Senate and over-ambitious consuls each ruling a few provinces and controlling several legions of the army. During the imperial era several changes were introduced to solve the problem of succession. In 494 BC the plebeians gained their own political organ, the Popular Assembly (a term that has already occurred in this narrative), holding the power to appoint two tribunes functioning as their own magistrates. All Roman citizens were constitutionally reckoned as members of the Assembly. In 450 BC the plebeians secured a code of law, called the twelve tables, formulated by an experts commission, which later formed the basis of all Roman laws. In 445 BC the two consular offices controlled by the Senate were changed to three tribunes with consular powers and open to both patricians and plebeians. A Censor's post was created, restricted to the patricians, with powers to control the register of citizens and senate members. With the exception of the poor farmers who were fortunate to have been settled in new colonies, as mentioned earlier, the majority of them before 390 BC were reduced to serfdom and were often bonded to masters belonging to the landed gentry because they had no resources to repay their debts except their physical labour. They had no legal right even to mortgage their own land. In 367 BC an agrarian reform law was enacted after protracted struggles in the Senate whereby a ceiling was imposed on the land holding of the landed aristocracy. A new system of land grant and availability of loans from special banks mitigated the problems of

the bonded labour. In 326 BC bonded labour was totally abolished and farmers were granted the right to mortgage their land. After 367 BC one of the two posts of consuls was reserved for the plebeians but it was provided that one consul could vet the other on any legislative issue. A new post of Praetor was created with the judicial powers of the consuls; both the censorship and praetorship were made open to the plebeians in 339-337 BC. In 287 BC a new legislation gave the force of law to the resolutions of the Popular Assembly. This was the highest point of the centuries old struggle of the plebeians for their political rights. Two brothers, Tiberius Gracchus and Caius Gracchus, members of an aristocratic family and well connected with many members of the Senate, later played a great role in completing the task of land reforms and redistribution of lands and they both had to lay down their lives in the hands of their adversaries. Tiberius, elected a Tribune by the Popular Assembly in 133 BC, established a law commission to implement the details of redistribution amongst poor farmers the excess land acquired from rich estates. In order to make money available for paying compensation to the land owners he appropriated the tax revenue of the newly formed Roman province in Asia created out of the gifted Attalid kingdom (133 BC). After the assassination of Tiberius (132 BC), his brother Caius took up his task. He worked as a land commissioner from 133 to 121 BC and formed and nurtured a coalition called equites (a term introduced earlier) comprising businessmen and traders, urban poor and the Italian Confederacy of the allies of Rome. He became Tribune in 123 and 122 BC and enacted legislations leading to: (a) establishment of new colonies, ports and trading cities for the rehabilitation of the urban poor and making food grains available to them at half price; (b) a programme of building road, harbours and other public works for which contracts went to businessmen and traders; (c) five - yearly contracts granted to the equites through auction for collecting taxes from the Asian province; (d) steps for granting full Roman citizenship and franchise to all the allies. Caius and a large number of his followers were murdered by his political opponents in 121 BC and as a result the demands of the allies remained unfulfilled till the Italian Confederacy set up their federal capital at Italica and fought a civil war against Rome (91-88 BC).

The Roman army was also very inefficiently organised in the beginning. It used to be raised from all sections of the population at the time of war, and the men had to provide for their own arms and armours. The poor farmers had to fight as foot soldiers and their small farms would be totally wasted and barren by the time they came back from a protracted war. Meanwhile, the rich landed gentry would remain unaffected and prosper because their farms used to be mostly worked with gangs of slaves and one or two bailiffs as supervisors. Marius, a Tribune in 119 BC and a Consul in 107 BC, recruited his army for the first time from the Roman poor on a wage basis and for a stipulated long enough period. He equipped them with standardised weapons and arranged for their training in new tactics. Extensive innovations were done by later generals raising the Roman legions to their undisputed military supremacy that lasted for several centuries.

The eastern empire which was under Hellenic rule at the time of their Roman conquest was never Latinised and the conquerors accepted the culture of the vanquished people as superior to their own. They even consciously imbibed that culture in the upper echelons of the Roman society. The wealthy gentry of Rome considered a Greek education imparted in Athens as the best that their sons could have; many of them kept highly educated Greek slaves as private tutors, secretaries, librarians and even as poets. Major part of the western empire comprising Spain and Gaul, on the other hand, was originally inhabited by tribal people thought to be 'barbaric' and inferior to the Romans in civilised norms; they were gradually latinised as is evident from the affinity of the present day languages of these regions to their parent Latin. Latinisation did not happen in Britain as well where Welsh and the Scottish languages are still rooted to their own origins and present day English developed from the language of the tribes of Germanic origin that came to Britain at the time of the collapse of the Roman empire under 'barbaric' onslaughts from the north.

Roman art and architecture of the republican period do not compare favourably with that of Athens in her brief period of glory. Roman talent was at its best in building a network of roads, bridges, aqueducts and city walls; during the imperial era Hadrian (117-138 AD) built a great wall in north of England as a protection against the Scotsmen (Caledonians). Antoninus Pius (139 - 161 AD) built a new wall in Britain from Forth to Clyde. When the Caledonians breached the Hadrian's wall at several places and over-ran the territory south of York and Chester, Septimus Severus (193 - 211 AD) throughly rebuilt it. Back in Europe Aurelian (270 - 275) defeated a German attack across the Danube and built a 12 mile long wall near Rome which bears his name. Roman architecture reached its height during the imperial days. Starting with Augustus beautiful temples, churches and other buildings were built by Vespasian, Trajanus (buildings in Trajan's forum are masterpieces of Roman architecture), Hadrian (responsible for prolific construction work in Athens, Tivoli and Rome), Constantine and Theodosius (churches in Rome and Milan), to name a few. Latin literature started in close imitation of the Greek literature in its various forms - poetry, fiction, drama. It has finally developed into an art form that has left a rich legacy, particularly for the Europeans. Romans failed to create anything original in philosophy and never attempted to imbibe the ideas and achievements of Athens in science - not even Astronomy; their only serious interests centered on Astrology for which rich Romans used to hire the Greeks. Rome's best legacy is in active political systems and law. Their military tactics gave them supremacy on the battlefield for several centuries but as time wore on, the northern tribes matched them in number and an iron will to win; perhaps they excelled the Romans in cruelty, savagery and sheer physical power of long term endurance of the rigours of a battle acquired naturally from their tough living conditions. The superiority of the Roman legions was then lost. It could have been preserved only by inventing better technology but in their long military history the Romans, except for some innovations in ballistics, had nothing to contribute because of their basic incapability to develop some rudiments of science.

As I have already mentioned, the imperial age was marked by several experiments in succession from one Princep to the next. For a time the dynastic law of succession was followed. Confronted with a situation of no sons or near relatives, a system of adoption of a suitable heir, to be initiated and trained during the life time of a ruling Princep, was then followed. That practice used to be interrupted whenever the Princep had an heir, resulting at times in the most inefficient or despotic rulers who were most often murdered by palace intrigues or by the Praetorian guards of Rome. With this vicious tradition, some very good emperors also lost their lives. On several occasions some of the legions annointed their own leader with the inevitable civil war amongst the adversaries. To avoid these circumstances, Diocletian (285-305) introduced a novel experiment by forming a board of 4 emperors who should divide between them four different parts of the empire - two of them called Augustus (Diocletian himself was one) would be senior and each would choose his own junior called Caesar. A fixed term of 20 years was agreed upon at the end of which the two seniors would resign and the Casears would be elevated to Augusti. Although Diocletian resigned at the stipulated time, his successor Constantine eliminated his rivals after a series of battles and became the sole emperor.

The period 193-476 AD is marked by historians as the period of decline and downfall of the empire. Even before this, during the period of so-called imperial peace the king of Dacia had invaded Roman territory across the Danube and there was a rebellion in the Roman army over the upper Danube. Emperor Domitian (81-96 AD) met the situation by entering into a treaty on dishonourable terms. Very soon Trajanus annexed Dacia (101-106 AD), expelled many local citizens to make room for setting up Roman colonies. Hadrian (117-138 AD) took great care of the army, improved discipline and introduced new tactics, and tightened the frontiers with new defence lines. Then came the barbarian invasion during the reign of Marcus Aurelius (161-211 AD) along the line of the Danube overrunning Dacia, the provinces on the Danube and reaching as far as the head of the Adriatic (166 AD). The emperor himself fought for 13 years and died of fever in an army post in Vienna. Septimius Severus (193-211 AD) relied heavily on his army and as expenditure mounted, introduced heavy taxation and even imposed compulsory labour and voluntary services thereby impoverishing the cities. In 235 AD war broke out again on the German frontier and the legions put Maximinus Thrax on the throne. Taxes, confiscation, requisitions continued and took a heavy toll. Commerce dwindled, cultivation suffered. The Goths reappeared on the Danube and began raids on the Danube land, Greece and Asia Minor. In 250 AD emperor Decius fell fighting them. The invaders captured a large part of the empire. In 258 AD a Germanic people called Alamanni invaded Italy and was checked at Milan. With the emperors so weakened, parts of the empire started looking after themselves independently. During his brief reign (268-270) Claudius Gothicus smashed the Goths in two battles and then Aurelian (270-275) pushed back the Germans across the Danube. He abandoned Dacia which was taken over by the Goths. By strengthening the Danube line he imparted a short lease of life to the empire. Diocletian (285-305) created a reserved army, laying emphasis on cavalry and raised frontier legions by

local recruitment. Once again the financial burden was met by heavy taxation and requisitioning free services of the craftsmen and artisans. Even tax collectors had to go without salary. Constantine, although magnanimous towards Christianity, could not stem the tide; taxation grew heavier, bureaucracy larger, more inefficient and corrupt. There was a veneer of mild prosperity till 350 AD. An outbreak of civil war in 353 AD saw mutual destruction of the finest armies of Rome when they were crucially needed against invaders. Julian cleared Gaul of an invasion by Franks and Alamanni but was himself killed in an ill-advised expedition to Persia. Britain was attacked by the barbarians in 367 AD and in 375 the Huns attacked the Gothland beyond Danube. A large number of Goths sought shelter in the Roman territory and when this was granted, they started an attack on Macedonia. Emperor Valens called troops from the east and was himself killed while counter attacking the Goths (378 AD). Next emperor Gratian capitulated by offering the Goth leaders responsible posts and permitting them to command their own armies. The defence of the Danube line was handed over to these hired mercenaries. The next emperor Theodosius then completed the folly by leading an army of Goths, Alans and Huns against an western army of Gauls, Britons and Germans who were really the proper Roman legionary. After his death his two sons divided the empire - Honorius ruling the west and Arcadius the east from Constantinople. The two halves were never reunited. In the west Honorius ruled for 29 years and his successor Valentinian II for 31 years. The real power passed on to ambitious barbarian military leaders. The Goths who were already settled inside the empire ravaged Greece and Illyricum and when they attacked Italy, a great general Stilicho stopped them. At the end of 406 a large horde of Vandals and Alans overran the Rhine frontier and poured into Gaul, ultimately ending up in Spain. Britain was severed from the empire. Stilicho was murdered by an ill-advised order of Honorius. Rome was captured by Alaric (410) who soon died in Calabria. After the Gothic king married Theodosius' daughter, the Goths were well settled as the barbarian protectors of Rome. The Vandals raised a Mediterranean fleet from Spain and finally occupied the African and Mediterranean possessions of Rome. Actius as the powerful army general virtually ruled the rest of the western empire. Then came the Hun invasion of Atilla. He ravaged Illyrricum, crossed Rhine into Gaul where he was defeated by an army of Goths, Franks, Alans, Burgandians, massed together by Aetius. Atilla attacked again the very next year and went back after the Pope met him. On his way he destroyed Aquileia; the people fled and founded Venice - an off-shore island. Atilla died in 453 and Aetius was assassinated by Valentinian III.

In the east Arcadius mostly copied manuscripts and channelled the Huns to the west by paying ransom. In 457 Leo I came into control and temporarily made a thrust on the Vandals in Africa. In the west, the barbarian generals took a lesson and safeguarded against the coming of a strong emperor; a string of puppets followed. In 476, Odoacer - the barbarian general - deposed the boy emperor Augustulus Romulus and himself became the Magister Militum of Italy. He pretended to have kept the unity of the empire by declaring that he ruled the west on behalf of emperor Zeno of

Constantinople. In the sixth century Justinian, emperor of the east, briefly revived the empire by conquering back Africa, Italy, Sicily and a part of Spain.

The Christian church had also split into two after the inaugural of the Byzantine church at Constantinople. Earlier the Pope at Rome was the sole Pontifex Maximus of the Christian faith and had introduced Latin in all religious services. The Byzantine Church maintained its Greek adherence although established by a Roman emperor. Constantine relied heavily on the Christian organisations to mould the mind and will of the citizens. The Christian Church, however, was too busy hunting down 'heresies'. In Persia Ardashir I who founded the powerful Sassanid dynasty similarly relied upon Zoroastrianism as the state religion with its organised priests and temples who were persecuting the adherents of all other religions. In 277 AD Mani, the founder of the Manichaeans, was crucified for his faith. Whenever Byzantium and Persia were not fighting the barbarians, they had been fighting each other, gradually reducing Syria and Asia Minor to a dreary waste. In the sixth century Justinian and Chosroes I were the adversaries, and by the seventh century Emperor Heracluis was facing Chosroes II who had by 619 AD occupied Antioch, Damascus, Jerusalem, Chalcedon (in Asia Minor) and Egypt. Heracluis retaliated by routing the Persians at home in Nineveh (627 AD). Chosroes II was murdered by his son Kabadh who entered into a peace agreement with Byzantium (628 AD). The eastern empire survived even after all this for several centuries and gradually faded out in history. For a long time the Pope of Rome kept up the show of crowning the rulers of Europe (starting with the great Charlemagne) as if a 'Holy Roman Empire' existed !

Some historians have cited several outbreaks of plague, lasting for more than 15 years, as one of the major reasons of the sapping vitality of the urban people in the Roman empire. It must have been one of the causes but certainly not a major one. As already stressed, the weakening of Roman military might for various reasons - political killings, murders for succession, civil wars, and the lack of any technological innovation to name a few - vis-a-vis the hardy Northmen was the direct cause of Roman decline and fall. If one wishes to explore a little bit deeper then more severe sociological maladies are not difficult to find. The production process was based on the toil of unfortunate, destitute, dehumanised slaves and serfs. For a long time the military might was based on the forced services of the poor who came back to wasted farm holdings and to discover that their livelihood had already been taken away by rich landlords employing slaves on their large holdings. At the other extreme the minority of wealthy aristocrats controlled an ever unstable political system and lived a life of luxury and very often indulged in debauchery and pleasures of flesh; the mind and soul of these masters of the society were throughly demented to the extent that the hideous spectacles of the arena, setting gladiators to fight and mutilate each other till death, throwing innocent unarmed Christians in the arena to be flayed by starved beasts, gave them ecstatic pleasure and relaxation. True, there was a very brief and famous revolt of the gladiator slaves under a leader called Spartacus and it was promptly subdued by Crassus, the lives of the ordinary men and women ruled by politicians like Sulla, Pompey or Crassus, were all along like a perpetual alley of

despair and darkness. For a time Roman citizenship was a prize possession but later it turned to be a mere appendage for most of the people. No wonder that such a society could not create during its long history what the small city of Athens did in a couple centuries ! The Roman social system did not educate the citizens to a set of values they cared for; only the Christian church with its well-knit organisation played some educational role amongst the people showing the path to a nobler life and making the promise of liberating their soul. Hence the Christian faith propagated and brought some hope and solace to the people at large.

2.10 Arab

When Heracluis and Kabadh were signing for peace (628 AD), a new era was being heralded in a small town called Mecca in Arabia. From time immemorial that desert country was the home of nomadic Bedouins of semitic stock who failed to develop an organised political system with a strong enough military power. Suddenly these people were awakened into an era of greatness spanning nearly a century when a new religion with its associated culture and outlook spread over a large area from Spain in the west, through the entire middle east to Turkistan in the east near the borders of China. All this was ushered in by the Prophet Muhammad who came into history somewhat earlier than 628 AD as the young husband of a rich widow. Islam is the new religion he preached and it is believed by his followers that he was the last prophet in the long line of Abraham, Moses and Jesus. He preached against idolatry and paganism, and talked of One True God. Koran, the holy book of Islam, was claimed as communications to him by God. Initially his monotheistic teachings created a strong resentment amongst the people of Mecca. When a plot was hatched to kill him, he escaped to Medina with his trusted follower and friend, Abu Bekr. His religion found a welcome acceptance in the new town. With time the enmity of Mecca also subsided and he made a triumphant return there in 629 AD. The prophet completed his task of imparting the power and inspiration of the new faith to the Arabs and passed away in 632 AD. One of the strongest point of his teachings was a perfect brotherhood of all men and their equality before God once they were initiated into Islam. Founding of the Islamic empire after his death was the signal achievement of Abu Bekr who was the first Caliph (successor), and several great Caliphs to follow him. The prophet himself had begun the task of dissemination of the new faith far and wide by writing a letter in Arabic to several monarchs of the world, including Heraclius, Kabadh and the emperor of China. Tai-Tsung, the Chinese emperor, welcomed the envoys and permitted them to build a mosque in Canton which still exists. The establishment of the Islamic empire was unique in the sense that it was done openly and explicitly in the name of Allah - to propagate the message of Muhammad and proselytize the vanquished people. The old and diseased Heraclius was defeated by a small Arab army in 634 in a battle on the Yarmuk, a tributary of the Jordan river. The Asian part of the Byzantine empire - Syria, Damascus, Palmyra, Jerusalem - came under Moslem possession. The next battle was fought against the Persians at Kadessia. After

three days of valiant fight by the Persian general Rustam, his army was routed (637 AD). The victorious Arab army continued on their trail of conquest through Persia to the east up to Turkistan, as already mentioned. Next they moved towards west taking Egypt almost easily in the absence of any Egyptian armed strength worth the name. Initially, the fanatic conquerors did certain things that were wrong - believing Koran is the only and ultimate book, they destroyed the book copying industry of the Library and Museum of Alexandria. The onward victorious march continued along the north coast of Africa, and then on to Gibralter and Spain (710 AD). The Pyrenees mountains were reached in 720, and thereafter the invasion was taken to the interior of France in 732 where the onward progress was stopped decisively and for ever. The man who inflicted the defeat on the Islamic army in Poitiers and made them retreat to the Pyrenees, was Charles Martel - Mayor of the Palace of a descendant of Clovis who had established a strong kingdom of Franks, a Germanic tribe, in this part of Europe. In 732, Charles Martel was the overlord north of the Alps from Pyrenees to Hungary. The famous Charlemagne who, as earlier mentioned, was conferred the crown as the Holy Roman Emperor by the Pope was the grandson of Martel. To come back to the saga of Arab conquest, the Moslems having acquired the Egyptian fleet, reached the vicinity of Constantinople by sea and tried to take the city in several onslaughts during 672 to 718 AD, but the Christian city withstood the assaults. Because of their political inexperience and doctrinal differences of later days amongst various factions, the Arab supremacy did not last too long. However, the Moslem domination continued for many centuries in the hands of the Turks and then the Mongols who also had adopted Islam at a certain point in their movement from their homeland towards the west into the middle-east Asia and India.

The initial fanaticism of the Arabs was soon replaced by a genuine love of and commitment to the fruits of human intellect as they came in contact with the Greek legacy in Egypt and Syria, and with the Indian contributions to philosophy, mathematics, chemistry and medicine. They also benefited by their affinity with the Jewish communities living at different places in their empire by learning from them the efficacy of arguments and discussions on old wisdom. In central Asia they learnt paper making and book printing - a technology transmitted there by China. Thus the Arabs, inspite of their initial wrong doings at Alexandria, later in their heydays of intellectual activity became the most ardent translators and publishers of all earlier works from all sources they could lay their hands on. For the first time, the Arabs established educational organisations which produced a class of learned men in the eighth and ninth centuries - their major centres being Cordoba in Spain, Cairo, Bagdad, Bokhara and Samarkhand. Even after the decline of the Arab political and military power, this intellectual class persisted for several centuries. At their zenith they left a brilliant record in astronomy, mathematics, chemistry and medicine. When contemporary Europe did not know how to write a very large number because of the clumsiness of the Roman numerals, they mastered the Indian knowledge in this field, including the use of zero, and transmitted the system to Europe where it is still known as Arabic numerals. The word Algebra is Arabic and the nomenclature persists because Arabs

played a dominant role in its development. Their contribution to Alchemy - preparation of alloys and dyes, distilling, tincture, perfumes - and invention of optical glass are well acknowledged.

2.11 China

I shall conclude the historical section of this article by next giving a short account of the civilisation of China - the cradle of one of the most ancient and mature civilisations of the world. For a long time the country remained virtually isolated from the other old centres of civilisation because of the very arduous land routes via central Asia connecting it to the others. Historians say that as late as the era when the Chinese empire had spread over an area larger than that commanded by Rome, and the Chinese culture had simultaneously attained a level superior to the contemporary Roman culture, the two great empires were hardly aware of each other's existence. Contacts were established between China and India during the Kushan empire of Kanishka, when the central Asian boundaries of the two touched one another. Visits to china by the Indian Buddhist monks and scholars and to India by Chinese travellers, interested in Buddhism, became frequent and continued over several centuries. Besides the land route, coastal shipping from Sri Lankas and Tamralipti in Bengal to present Cambodia, Laos, Vietnam and southern China also helped maintaining contacts. Fa Hsien, the famous Chinese traveller, for example, came to India by the land route and went back to China by sea. Followers of Muhammad who carried his message to the Chinese imperial court also used the sea route. However, journey by the coastal boats was also as perilous (Fa Hsien's account details his hazardous experiences) as that by land. Trade and commerce in the prized produce of China, India and countries as far as the Mediterranean coast used to go on with caravans moving both ways along the land route, called the 'silk route' in honour of the finest Chinese silk - one of the important items in this trade from the Chinese side. However, the caravan traders who used to relay the goods, would come into contact with only their counterparts meeting them at tradeposts within a reasonable distance from each other's home. As a result the Chinese traders, or the Indian traders knew very little of those near the Mediterranean and beyond, and vice versa. During the Eastern Han regime (25 - 220 AD) a famous Chinese general, Ban Chou (old spelling: Pan Chow), was sent (73 AD) to the so called oasis kingdoms along the Central Asian desert routes inhabited by different tribes who used to be constantly plagued and pillaged by the namadic Xiongnu (the white Huns) from Mongolia. The general stayed there for 30 years, freed these tribal kingdoms from the onslaughts of the Huns and brought them under Chinese sovereignty. In 93 AD Ban Chou had sent an emissary to Persia, who went up to the Persian gulf and came back with some second-hand informations on the Roman empire beyond the Persian borders on the west. According to Hanshu (History of the Han dynasty) the first direct contact with Rome was established in 166 AD when the Roman emperor (Marcus Aurelius) sent an envoy to China by sea.

The Chinese history is very well documented, thanks to the tradition and proficiency of the Chinese in maintaining records of all kinds. The period prior to 21st century BC is called the legendary period by the Chinese historians. The rich archaeological records of this period include (i) a fossilised ape man about 1.7 million years old, (ii) the famous 'Peking man' who used stone tools, lived in groups and knew the use of fire, (iii) relics in caves near Beijing (Peking), about 18,000 years old, of men living in a society, using stone and bone articles pierced with holes, wearing clothes of animal skin, adept in catching fish and lighting fire, (iv) 8,000 year old ruins of Banpo clan near Xian (Old Chan-an) in the north in the Huang Ho (Yellow river) valley and of Hemudu clan in the Yangtze river valley who used ground and polished stone tools, bows and arrows, raised crops and domestic animals including oxen, liked settled lives in wooden houses and have left pottery as relics with symbols that are rudiments of Chinese characters, (v) sacrificial altars of stone, painted clay heads of goddesses, ceramic statuettes of women, polished jade and stone ornaments, one sample each of a dragon, pendant and bracelet - all of jade, approximately 5000 years old, (vi) emergence of a wealthy feudal class owning slaves, starting about 4-5 thousand years ago, evidenced by tombs containing a large number of valuable funeral objects that included slaves! Approximately 4000 years ago consolidation started amongst major tribal groups inhabiting the yellow river valley, and Huang Di (the Yellow emperor) established a small unified nation called Hua Xia, after defeating other tribal leaders. The names may be legendary but there may be some truth that these people built boats and carts, composed simple musical rhythms, initiated some arithmetic, medicine and written characters. Wealthy tribal chiefs constituted an aristocracy by and by and thus originated a feudal society dependent on the labour of people forced to slavery. Some of these unfortunate people were originally taken prisoners in group skirmishes, and some were really bonded labourers who owed debts to their masters.

Starting from 21st Century BC, the various periods marked in Chinese history up to the commencement of the first empire, are:

Table 2

1. Xia (21st - 16th Century BC)
2. Shang (16th - 11th Century BC)
3. Zhou (Chow: earlier spelling)
   (a) Western Zhou (11th Century - 770 BC),
   (b) Eastern Zhou - (i) Spring and Autumn (770-476 BC) and (ii) Warring States (475-221 BC)
4. Qin (Chin or Ts'in: Old spelling) - (221 - 206 BC)

Xia dynasty was founded by Yu. Jie was the last king in the chain of hereditary succession. Tang, Chief of the Shang tribe, seized power from Jie. Both these kingdoms stretched on the two sides of the yellow river and extended a little bit to the south into the Yangtse valley. At its height the Shang kingdom covered a bigger area than

Xia in its prime. The rulers were all despotic and relied heavily on the army, the penal laws and the dungeon. Various handicrafts, specially glazed pottery, carving of jade and stone, and bronze castings, are amongst the important relics of the Shang period. A rectangular ritual bronze cauldron weighing 875 kg, 133 cm high and 110 cm long, has been found in the Shang ruins. First coins in China, made of bronze, were introduced during the Shang period. This dynasty came to an end when the ruler of the small Zhou kingdom defeated the Shang king. The Zhou dynasty established its capital at Hao (later Chang-an, modern Xian in Shaanxi province). The king was declared as the 'son of heaven' and the owner of all the land. The nobles and the princes received their huge shares of land from the king, they in their turn distributed a part amongst their subordinate officials, and so on down the line. At the end of the line eight peasant families used to form a group and receive a piece of land subdivided into nine patches; the produce of the central patch used to be collected as tax. Slaves were used in both agriculture and handicrafts. Crafts proliferated and the age became known as that of the 'creation of hundred jobs'. The commoners had to serve in the army whenever needed and as a result they were perpetually impoverished. There was a temporary upheavel against the Zhou king in 841 BC and finally in 770 BC king Ring attacked by a tribal force, had to shift his capital to Loyang to the east of the earlier capital near Chang-an. Thus began the Eastern Zhou period. During the Spring and Autumn part of Eastern Zhou the kingdom was fragmented under numerous local rulers with their respective headquarters; about eight or nine of these so - called dukedoms were quite powerful and were constantly engaged in skirmishes to subdue the others. All the time the power of the Zhou king dwindled so much so that in 651 BC he recognised the ruler of Qi as an overlord by sending an emissary to his court when the latter summoned a meeting of alliance after defeating about thirty small rival dukedoms.

Even at the beginning of Xia period China had introduced a calendar. The first record of a solar eclipse in world history has been found in oracle inscriptions on tortoise shells belonging to this period. Fortune telling was common during Xia and Shang periods which gave rise to the oracle inscriptions on shells and bones of which more than 100,000 pieces have been discovered in old ruins in the present century. The inscriptions are in a well developed written language. During the Shang period China had learnt the use of decimal system in Arithmetic, and made considerable progress with complex geometrical figures. A book of documents (Shang Shu) of this period has been found with a compilation of ancient documents and represents the first known prose work in China. A book of songs - a collection of folk songs and poems - has also been discovered. Surprisingly this book gives the exact time of an actual solar eclipse. Chun Qui, the Spring and Autumn annals, records the earliest observation of a comet. Inspite of the political fragmentation and instability of the Spring and Autumn period, as already described, major philosophical thoughts - Confuianism and Taoism - which have played a lasting role in the development and flourishing of Chinese culture - date back to this period.

Confucius (K'ong Fu-tseu in Chinese) and Lao-tse (the propounder of Taoism) were contemporaries of Gautama Buddha, the former slightly younger and the latter slightly older than Gautama. They died also a few years after and ahead respectively of the Buddha. Confucianism was more a codification of political and social ideals than a religion or philosophy. Confucius prescribed the ideals (like Plato did some centuries after him) for the individual as well as for the states. He was a believer in T'ien which, although translated as heaven, does not denote a place - it represents an omnipresent, omnipotent principle, inaccessible to the senses, and is the giver of the great law of moral code for the ruler and the ruled. On the micro-scale the law requires the head of a family to do his duties to his family members and treat everyone with filial piety; in return his offsprings are to obey and respect him and, after his death, perform prescribed memorial rites. (Ancestor worship was prevalent in the Chinese society from centuries before Confucius). On the macro-scale similar codes were prescribed for the ruler and his subjects. Originally an important administrator, Confucius, like Plato many years later, looked for a king or prince who would implement his ideal codes but died a disappointed man. However, Confucianism flourished in China for many centuries after he passed away. Lao-tse developed a philosophy which, he himself claimed, was a compilation of the existing wisdom. As the Librarian of the state library he had access to many old works. He left the word 'Tao' undefined, asserting it cannot be described in words. It approximately means 'the way' or 'the principle of wisdom' - the transcendent and immanent principle behind everything, realisable only subjectively. Before all times, it was self-existent, eternal, infinite, omnipresent and perfect. Beyond all senses, at the beginning nothing but its essence existed possessed of two qualities - 'Yin' (concentration) and 'Yang' (expansion). The universe of name and form arose with the exteriorisation of this essence. The state of 'Yin' is the true state and the state of 'Yang' causes manifestation in perceptible beings. The human mind has two similar states - one of activity, passion and disturbance with many ideas and images, the other of repose when the mind becomes transparent like a clean mirror on which 'Tao' reflects itself. This state is to be reached by prescribed practices of meditation and control of breath, and by renouncing all conventional knowledge and activities. Clearly, Taoism is, in principle, close to the Upanishadic doctrine of 'Brahman'; at the same time the state of mind of a Taoist sage has similarities with the Mahayana Buddhist doctrine of 'emptiness'.This explains why Mahayana appealed to the intelligentsia and elite of China. It is a great tribute to the openness of the Chinese mind that the two great traditional wisdoms of China were finely interwoven and blended with Buddhism in the lives of common men when it arrived there and thrived for centuries.

During the Warring States period the Zhou kingdom became so enfeebled that it became a near equal of six other states - Qi, Chu, Yan, Han, Wei and Qin - that balanced one another. Wei and Qin introduced many land reforms. Qin, particularly, abolished the hereditary aristocracy and inheritance of official positions by the family members of the nobles. Shang Yang (390-358 BC), the king of Qin, was murdered at a crossroad with horse-driven carts in a conspiracy by the disgruntled conservatives. On

the whole, the kingdoms of this period have a lot of achievements on record: farmers learnt the use of iron implements, biological manures and select seeds; irrigation was introduced for the first time; small industries each employing up to several hundred workers grew up for iron smelting, casting and forging to make tools; salt industry came up in a big way. The new owners of industries became as rich as the landed aristocracy. Circulation of currency increased leading to money lending in the society for the first time. Small cities of 50 to 70 thousand population grew up. Many developments took place in mathematics (definition of a circle more than 100 years ahead of Euclid), methods of observation and diagnosis (similar to the Indian system) were developed in medicine. Carpenter Lu Ban became famous for his construction of buildings, bridges, wooden horses and carts, and various bamboo artefacts. Scholars sprang up in many fields with their disciples propagating the so-called 'one hundred schools of thought' of which Mohism, Confucianism, Taoism and Legalism played a major role. Several books of history and political thoughts belonging to this period are available. Some of the poems in Qu Yuan's (340-278 BC) 'Book of Songs' has been translated into many languages. The art of bronze objects soared to great heights with beautiful inlay work in gold and decorations in relief. Murals and paintings on silk were also developed.

Gradually Qin excelled the other six states in power and started its onslaughts by annihilating Zhou in 260 BC, and then easily defeating the others after buying off their officials. The united kingdom established its capital at Xianyang (near modern Xi'an). Qin Shihuang (Shi Hwangti according to western authors) came to the throne in 246 BC and took the title of 'Emperor' in 221 BC. Thus Qin entered history as the first consolidated Chinese empire. The emperor set up a centralised dictatorial administration by appointing a premier, grand marshal and grand censor in charge of administration, military affairs and supervision of all officials respectively. The whole country was divided into prefectures and each prefecture into several counties - all the officials for their administration being appointed by the emperor. Western authors call this political system 'oriental despotism'. It prevailed quite successfully for nearly two thousand years. Uniform feudal decrees, standardising scripts, currencies, weights and measures, and construction of 'imperial chariot roads' radiating from the capital - were some of the immediate achievements. Emperor Shihuang became famous for starting the construction of the great wall by linking the old ones constructed by some of the earlier kingdoms (Zhao and Yan, for example).

Apart from the fact that this great emperor extended his territory to the sea in the east and south, the great wall to the north and Gansu in the west, his long reign of 36 years is otherwise very undistinguished. He had ordered burning of historical records other than those of Qin, and burial alive of dissident Confucians and alchemists. His military expedition against Xiongnu to the north of the imperial border was unsuccessful. In his regime peasants were taxed upto 2/3rd's of their produce and were further subject to compulsory labour (corvée) in lieu of additional tax. For his construction work on the great wall, chariot roads and prestige buildings he conscripted nearly 1/10th of the population, including women. Hundreds of people died

of hardship and many were thrown into 'prisons as large as cities' by imposing harsh penal laws. The situation further deteriorated during the reign of his successor which is called the 'government of darkness '. After an abortive insurrection led by two army men, who were later killed by their own subordinates, Qin regime ended in 206 BC when Liu Bang captured the Qin capital in a decisive battle and established the Han empire with Chang-an as capital.

The political history of the dynasties between Han and Tang are condensed in the following table:

Table 3

Western Han (206 BC - 8 AD);
Xin (8 - 23 AD), Gengshi (23 - 25 AD);
Eastern Han (25 - 220 AD)
Three Kingdoms:
Wei (220 - 265 AD),
Shu Han (221 - 263 AD);
Wu (222 - 280 AD)
Jin: Western Jin (265 - 316 AD), Eastern Jin (317 - 420 AD)
Southern and Northern dynasties (420 - 589 AD):
4 Southern dynasties ruled from Nanjing and 5 northern dynasties
from different places near Loyang.
Sui (581 - 618 AD)
Tang (618 - 907 AD)

The Han regime inherited from Qin a shattered economy and a devastated population. By abolishing the oppressive penal laws and distributing land and title liberally the new rulers rehabilitated the dispossessed farmers and farm labourers. The demolished army men were also granted farm land in compensation of their unpaid military services. There was a complete exemption of tax for the farmers for ten years and thereafter a tax was levied at 1/15th of the produce which used to be reduced at times to even 1/30th. The traders and merchants, however, had to pay a property tax. With extensive use of iron implements, water conservancy and flood control measures, agriculture prospered tremendously. On the industrial side, salt and iron trades were monopolised by the state. Officials were employed to impose price control and supervise transport of goods and industrial raw material. Iron smelting workshops and mining of coal proliferated. Silk industry also reached great heights in both volume and artistic quality of production. The city of Chang-an at this time was nearly thrice as large as contemporary Rome. Fortunately or unfortunately, the hundred schools of thought were prohibited and only Confucianism was accepted officially in political and social management and discourses. After a period of harassment by Xiongnu on the northern borders, two Han commanders took a fierce offensive onslaught and pushed the enemy back to Mongolia. Envoys were exchanged with the oasis kingdoms in Central Asia and these were brought under Chinese protection after freeing them

from the menance of Xiongnu. This led to the opening of the 'silk route' along which Indian Buddhism very soon reached China. Around 60 BC a General Inspector's office was. opened by China for this area-designated as 'Western region' by Chinese historians - to manage the political and military affairs. The large number of small tribal kingdoms in the south-western region (Yunnan, Ginzhou, Sichuan and the Yue nationality scattered over Fujian, Guangxi etc.) were also brought under the empire during the Han regime. After emperor Wu's death there was a turmoil during which a relative of the royal family assumed power in 8 AD and ruled quite benevolently till 23 AD. A famine in 17 AD put his administration to severe strains. Under multipronged rebellion attacks, the ruler was killed and for two years another usurper tottered on. In 25 AD Liu Xiu proclaimed himself Emperor Guangwu and reestablished the Han rule (eastens) from Lo-yang as his capital. By 26 AD the new emperor crushed all the rebellion armies and reunified the empire.

Emperor Guangwu (25 - 57 AD) set the slaves free, reduced corvée labour for the peasants and land tax to 1/30th of the produce, introduced water conservancy, built protective embankments, started dredging silted river beds and lakes and dug canals for irrigation. Emperor Ming (58 - 75 AD) following him, engaged an expert for controlling the floods of Hwang Ho, and the flooded land in the lower reaches of the river, after the recession of the flood, started being put to cultivation as rich fertile farm land. Du Shi invented (38 AD) a blast furnace operated by water power - a type that was introduced in Europe as late as the 12th Century. Bronze casting attained a new level of excellence and the Chinese extensively introduced the use of oil as a fuel. The total agriculture and industrial output of Eastern Han even exceeded that of the Western during the latter's peak. The Xiongnu, at this time, got divided into northern and southern parts of which the southern people moved into Shanxi province and merged with the Chinese population. the Northern people still went on pillaging the northern border areas of China and also made incursions into the central Asian kingdoms. As already stated, the problem was solved by despatching Ban Chao to the Western region in 73 AD.

Legends have it that the Yue-Che king of Baktria had sent some Buddhist texts and icons to the Chinese Emperor's court. Emperor Ming then dreamt of a golden man who, he was told, was Gautama Buddha. The Emperor sent his emissaries to the Baktrian ruler who sent back two Buddhist monks, Dharmaratna and Kāshyapa Mātanga, along with a white horse laden with Buddhist scriptures. The Emperor received them and built the famous White Horse Monastery (Po-ma-sse) in Lo Yang as their residence. The monks stayed there, preached the dharma and translated the books they had brought with them. The Po-ma-sse historically existed and served as a cradle of Chinese Buddhism. In 148 AD An-she-kao (Lokottama), a Parthian prince, who had adopted Buddhism after abdicating the throne, came to the Chinese court and from then till the end of the Han dynasty in 220 AD there was a great surge of activity in acquiring Buddhist texts and translating them into Chinese. Initially this was a private job undertaken by a few masters with small teams of their disciples.

After the fall of the Han dynasty in 220 AD there was a short civil war amongst three power centres: (1) Wei kingdom that was formed after deposing the last Han emperor at Loyang, (2) Shu-Han based in Chengdu, and (3) Wu with capital at Nanjing (Nanking). Later the kingdoms co-existed peacefully and all of them achieved an upward surge in agriculture by water management, introducing new methods of farming amongst the hill people and bringing more land under cultivation. Shu established a prosperous silk industry with export channels to Wei and Wu. The latter, in the south of Yang-tze, took shipbuilding technology to great heights - the ships built could each carry upto 3000 people. For the first time a fleet was sent to Taiwan (230 AD). While Wu and Shu declined with time, Wei became more and more powerful. In 265 AD a member of the Sima family of Wei defeated Shu and declared himself Emperor Wu of Western Jin (Chin), keeping Loyang as his capital. In 280 AD Jin conquered the Wu kingdom as well and achieved reunification of the empire.

Starting before the Western Jin regime, the northern border area of the empire were inhabited by various Mongolian tribes - Xiongnu, Xionbei, Jie, Di and Qiang. At the beginning of Western Jin these people started moving into the imperial territory and were being exploited in various ways, including being sold as slaves, by the Chinese feudal lords and officials. During the ensuing revolt by these people, a Xiongnu warlord captured Loyang (304 AD) and ended the Western Jin rule. Many of the panicky aristocrats, officials, and peasants migrated to Nanjing region and in 317 AD they installed a member of the royal house of Western Jin, who was amongst the fugitives, as the new Jin Emperor (Eastern) with his capital at Nanjing. In the north in the Yellow river valley, the Mongolian tribes carried on skirmishes for supremacy and sixteen different regimes were established between 304 and 439 AD. In 383 AD several of them joined together under the Qian king and attacked Eastern Jin with a huge army. However, they were defeated due to their own tribal dissensions and Eastern Jin consolidated itself by gaining some more territory to its north in the Yellow river valley. Eastern Jin was ended in 420 AD when an ambitious general captured power and declared himself Emperor Wu of Song. As has already been shown in Table 3, four southern dynasties, including Song, ruled one after another from Nanjing between 420 and 589 AD.

In the north the different warring groups were first consolidated together in 386 AD by the Xianbei king who proclaimed the establishment of the Northern Wei dynasty. The unification of the Yellow river basin under Wei was completed in 439 AD. By that time the Mongolian invaders had given up their nomadic life and got integrated into the settled social fabric of the original Chinese feudal society. Emperor Xiaowen established a good relationship with the Chinese aristocrats and introduced many land reform measures. He promoted intermarriage with the Han population, encouraged Han surnames, language and clothes for his own Mongolian people and thus ensured the formation of a unified nation in the Yellow river basin. In 494 AD he shifted his capital to Loyang. After his death feudal overlords started fighting one another and there was a rebellion amongst soldiers in several garrison cities because they were cheated of their pay and rations by their corrupt generals. The rebellion

was suppressed but it ultimately led to the end of Northern Wei in 534 AD. Four more northern dynasties (see table 3) followed; the last one Northern Zhou ruled till 581 AD. In that year the maternal grandfather of the Northern Zhou king seized power and declared himself Emperor Wen. In 589 AD he defeated the last king of the then southern dynasty (Chen) at Nanjing and once again unified north and south under the Sui dynasty (581-618 AD). An all-round prosperity was achieved during the Sui regime. City of Daxing (modern Xi'ang) was the capital and it was built extensively over an area of 84 sq. km, unheard of any city in those days. The forbidden city and the imperial palace were well laid out. the city of Loyang was chosen as the eastern capital and extensive building activities were undertaken there too. The last Sui emperor Yang started digging the grand canal which, when finished, connected five large rivers, served as an important transport artery between the north and the south and as the largest water conservancy project of the world. Boat building technology made a great advance - warships were built with 5-storey deckhouses. Towards the end of his rule the emperor built a huge fleet and in 612 AD launched an adventurous attack by land and sea on Korea with one million men. However, a catastrophic defeat ultimately ushered in the downfall of the empire in 618 AD when an army general Li Yuan occupied Changan and took the title 'Emperor Gaozu' of the Tang dynasty (618-907 AD). He abdicated in favour of his son, the famous emperor Taizong (Tai-Tsung / Tai Chung: earlier spelling) who killed all his brothers and ruled from 627 to 649 AD. He established an efficient ministerial system of governance sensitive to the miseries of the people and reasonably free of corruption. The next emperor Gaozong (650-683) issued the first set of written Chinese laws all over his empire. Taking advantage of his ill health Empress Wu Zetian took control in her own hands and after the emperor died (690 AD) she declared herself the empress - the only one in Chinese imperial history - and remained at the helm till 704 AD.

Upto the end of Emperor Xuan Zong's rule (712-755) the Tang empire passed through a very prosperous period marked by all round achievements. During the reign of Taizong Turkistan got divided into western (to the north of the Tien Shan mountains) and eastern parts. Taizong sent an army, brought the eastern Turks under Chinese sovereignty and set up a governor's office, appointing the governor from the Turkish nobles. In 640 the same emperor installed a Chinese General Inspector near Turfan to keep peace in the western region in central Asia, and later moved the Inspector's office to Kuchi. In 702, during the rule of the Empress, a similar Inspector's office was established with jurisdiction over a vast area to the north of Tien Shan and also in the Altai mountains. During Emperor Xuan Zong's regime several tribes were brought under Chinese command and the tribal leaders were appointed as heads of governor's offices. The major achievement of the Tang regime was to extend its hegemony up to the Tibetan plateau where the Tubo people, the ancestors of modern Tibetans, had been living for many centuries and had evolved a society based on agriculture and handicrafts. First, Taizong sent one of his princesses in 641 AD with bridal gifts to the Tibetan capital to be married to the Tibetan Chief. In 710 AD another Chinese princess was sent on a similar mission and an agreement of alliance

and friendship was achieved between Tang and Tibet. Extensive cultural contacts and exchanges were developed during the Tang empire with India, Persia, Arabia, Korea and Japan. Besides the two capital cities which were the hub of commercial activities, a large number of small trading cities came into being doing brisk business. Several large port cities were thriving and a Commissioner of foreign trade used to supervise the maritime commercial activities.

The decline of Tang started in 755 AD with the outbreak of the Anshi - rebellion started by a military governor general. It was defeated but erupted again until finally put down in 763. Taking advantage of the weakness of the central government, many military governors seized local power, and plunged the country into a chaos by fighting one another for supremacy. The central government was seized with a clique of powerful eunuchs (happened earlier also in Chinese history) who set up 7 kings and killed 3 during this period of turmoil. The government tried to collect more tax revenue from the landlords but the latter passed on the entire burden to the poor peasants; corrupt officials further ensured that there be a loss, rather than an increase, in tax collection. Desperate emperors levied taxes on the harvest before it ripened, also on salt and tea causing immense misery to the people. Several salt peddlars led a rebellion around 880 AD which grew and spread mobilising nearly 6,00,000 men who marched northwards, after crossing the Yangtze. They captured both Loyang and Chang-an and emperor Xizong (874-888) fled to Sichuan. The Tang army regrouped, counterattacked and quelled the revolt, prolonging the life of the empire by a couple of decades. A renegade general of the insurrectionary army became a Tang military Governor General and gradually developed his own power. In 907 he deposed the Tang emperor and founded a new kingdom called Liang.

I shall now present the history of Buddhism in China up to the end of the Tang period which is the terminal point of this historical account. As already mentioned, Buddhism entered China during the Eastern Han regime and was restricted up to the early third century, to translating canonical texts on the private initiative of a few masters with their teams of disciples. Its subsequent spread in the north and south, sprouting of monasteries large and small, swelling in the ranks of monks and nuns, prolific translation works, adoption of Buddhism by the monarchs, and indigenisation of the philosophical aspects leading to typically Chinese sects etc. deserve a few paragraphs. But, first some details on the logistics of communication over many thousands of miles from the original centres of Buddhism in eastern and central India to China proper. From my first hand experience I know, many Indian students of history are not fully aware of these details - very few of them can enlighten a curious enquirer about how Fa-Hsin or Huen-Tsang travelled to India and back.

During Buddha's days a great east-west highway existed between Rājagriha in Magadha to Taxilā (and even beyond to the foot hills of the Hindukush). Emerging at Rājagriha the caravans used to cross the Ganges at Pātaligrāma (later the garrison city of Pātilaputra built by Ajātasatru) by ferry boats and then the route went through Vaishāli - the capital of the republic of Lichhavis, Pāvā and Kushinagar - the two capitals of the Malla republic, Kapilavastu - the capital of the Shakyas (Buddha's

own people), Sravasti - the capital of the powerful Kosala kingdom where the road bifurcated. The minor branch used to go south through Ayodhya/Saketa, Vārānasi, Avanti to Ujjain, while the major east-west route went through the kingdoms of Panchala, Kuru, Madra ending up in Gāndhāra (capital at Taxilā). Buddha disseminated his teachings, frequently travelling on foot from Rājagriha to Vaishāli, Pāvā, Kusinagara, Kapilavastu, Sravasti, Rishipātana (near Vārānasi, present Sārnath) and a couple of times to Koshambi. From Pātaligrāma people used to travel farther east to Angadesha (capital at Champā, present Bhāgalpur) and from there by commercial boats to Tāmralipti (present Midnapur of West Bengal). From Tāmralipti seagoing vessels used to carry people and merchandise to Subarnabhumi (present Burma), Siam (Thailand), Kampuchea, Annam, Javadwip and Canton in China (Chindesha to Indians). From Taxilā Buddhist monks and scholars used to travel via Purushapura (Pesawar), Bamyan (at the foothills of Hindukush with relics of a rockcut Buddhist monastery, at present in Afganisthan, with two huge statues of Buddha which are very much vulnerable under the present political conditions) and through passes in the Hindukush following the Kabul river (ancient name Kuvā) finally emerging in Baktria. After the propagation of Buddhism by Ashok and Kanishka many Buddhist centres had come up along this route and even in Parthia to the west of Baktria. From Parthia the road going west finally merged with the ancient highway connecting Babylon with the ports on the eastern Mediterranean. All the roads to China used to emanate from Baktria. The northernmost one crossed the rivers Oxus and Jaxartes and went through Sogdiana, past Tashkent, through northern Turkestan - all the time staying north of the Tien Shan mountains - and finally emerging through mountain passes in Tien Shan near Tun-Huang at the entry point to China proper. The more frequented routes - northern and southern - ran along the northern and southern fringes respectively of the horrid Taklamakan desert in Central Asia, the former keeping to the south of Tien Shan and the latter to the north of the Kun Lun ranges. These two routes emerged from Kashgar on the west of the desert and ended up at Yu-men-kuan (Jade Gate) on the east near Tun-Huang. Kuchi, Agnidesha (Karasahr), Bharuka and Turfan on the northern route and Khotan, Dandan Uilik, Endere and Miran on the southern route had developed strong Buddhistic traditions. Kuchi, Agnidesha and Khotan had ruling familites with Indian names and most probably Indian ancestry as well. In particular, it is said that Ashok's son, Kunala, who was governor of Taxilā, left his post with a few faithful officials, fearing assassination attempts by his step brother who succeeded Ashok to the throne at Pātilaputra. He finally reached Khotan and established the local Buddhist ruling dynasty with Indian names. The other places of Buddhist traditions were most likely to have been evangelised during Kanishka's days. In some of these places, due to later Persian influence, Sanskrit and Pali texts have been found, written in the Kharoshthi script. Khotan had a great Buddhist monastery called Gomati Vihara, which was a very active intellectual centre specialised in training monks in different languages who provided an experts' pool for jobs of translation. To reach Kashgar from the Navasangharama Vihara in Baktria, the route lay across the Pamir to a place called Tash Kurghan to

the east of the plateau where the most direct route (seldom used because of the great mountaineering skills needed to negotiate it) from Kashmir via Gilgit came down the mountains and met the usual route I have been describing. From Tash Kurghan to Kashgar the road was easy and lay on the plains. On the Chinese side, proceeding south-east from Tun-Huang the travellers reached Chang-an and then Lo-yang. Initially Indian, Indo-Scythian and Parthian monks and scholars followed the Central Asian routes described above and Buddhism was spread by them in the north of China in the yellow river valley along the east-west line connecting Tun-Huang with the western and eastern capitals. After some time when Buddhism established itself on a secure foundation in China the reverse flow to the Buddhist centres in India started. Chinese monks, scholars and pilgrims visited India (entering from the north-west and then travelled extensively along the east-west high way complex to Sravasti, Sārnath, Kapilavastu, Pāvā and Kushinārā, Vaishāli, Pātaliputra, Rājagriha and the great university of Nālanda close to it, and finally Buddha Gayā on the river Niranjanā where the Lord achieved Nirvāna and became the Buddha. Near the entry point to India they used to visit Nagarahāra, a town in Buddhist traditions, the city of Purushapura with its unique Pagoda style stupa (only one of this type in India) built by Kanishka on the Lord's relics in a silver urn, and the Dharmarājikā Stupa in Taxilā. At a later date the stupa at Sanchi, Mathura (the centre of Gāndhāra art) a famous university at Vikramshilā in the east (near Champā) - also became a part of the pilgrimage. One of the main concerns of those travellers was to collect Buddhist texts and icons to take back to China. The Chinese emperors were also interested in treatises on Indian medicine and alchemy.

After the fall of Eastern Han and during the ensuing periods of Three Kingdoms and the shortlived unification under Western Jin, Buddhism so far confined to the north spread to the south, specially to the south of Yang-tze in Nanjing, Hang Chow and Shoo Chow. In the north the number of monasteries and followers of Buddhism increased considerably under a sinicised Indo-Scythian monk, Dharmaraksha, from Tun-Huang. He is credited with the translation of about 150 scriptures including a few classics of Mahayana. Around 260 AD the first Chinese pilgrim, Chu-Shih-tzing, went to Khotan and brought back some scriptures. The Vinaya code was also brought to China for the first time during this period. In the south, the situation was quite different; in the absence of experts, only a few non-authentic translations, more suited as popularised versions for the laity, were available.

Farther south Chinese hegemony extended, starting in the Han period in 111 BC over the northern parts of Vietnam, and continued for about 1000 years. The sinicised upper stratum there adopted Buddhism.

Anti-Buddhist arguments in China were directed against the Buddhist promise of enlightenment for laymen and nobles alike and also against the monastic order because (a) the monks lead a parasitic life, (b) they leave their families which is against the Confucian moral tenets, and (c) the sangha claims autonomous status outside the jurisdiction of the state's political power.

During the Three Kingdoms and Western Jin periods many elites and Buddhist monks from the north migrated to Nanjing area. As a result Buddhism in the south, patronised by the upper stratum, had an innate tendency towards intellectualism. Mahayana with its intricate philosophy thus appealed to these people. Incidentally, this was the beginning of the development of an indigenous Chinese Buddhist philosophy. A large number of monasteries grew and became centres of learning. The Jin emperor himself adopted Buddhism in 380 AD. With direct royal support Buddhist institutions flourished. Fa-Hsien (317-420) travelled to India and came back after 14 years during this period with a huge collection of canonical literature which was laboriously translated into Chinese under his direct guidance. Emperor Wu (520-549) of the subsequent Southern dynasties was also a Buddhist and gave tremendous patronage to the dharma. He himself took the Bodhisattva vow in religious assemblies. In the north, the Mongolian kings of the Northern dynasties always supported Buddhism as a counter against Confucianism prevalent amongst the Chinese aristocracy. Taoism, however, became a powerful antagonist and contributed to outbreaks against Buddhism in 446 and 574 AD.

Kumarajiva, the famous scholar prince from Kuchi, came to Chang-an in 402 AD and organised a powerful group of translators. Imperial support reached its peak during the proto-Mongolian Western Wei regime (northern dynasties). There was an upsurge in temple building. In 518 nearly 1/3rd of LoYang was dotted with Buddhist buildings, many of them with full pagodas. Because of their wooden architecture none of them survived the passage of time. Impressive monuments that still remain are the cave temples (i) near Tun-Huang dating back to 400 AD, (ii) Yun-Kang caves near the first Wei capital in Shaanxi, and (iii) Lung-min complex near LoYang. The big monasteries gained from liberal land donations and assignment of free labour of peasant families. During the Wei regime the number of monasteries and monks and nuns rose to 30,000 and 2 million respectively. However, the emperor kept a supervision over these establishments through his officials. The large number of small village temples developed a popular kind of worship of Bodhisattva Maitreya, a future Buddha who is expected to appear and rescue everyone from sufferings.

Buddhism had become a permanent force by 581 AD when Sui reunified the north and south. Buddhism had permeated into the society at all levels. The Sangha had grown and the job of translating all the available canonical texts was complete. Foundation was thus laid for creative developments in the hands of the Chinese masters during the Sui and Tang periods when the empire had flourished to its zenith. The founder of the Sui dynasty called himself 'Chakravartin' (mover of the wheel of dharma), a saintly ruler in the Buddhist tradition. The famous Empress Wu used Buddhism to justify her seizure of power by claiming herself to be an incarnation. Successive rulers maintained their state temples for rituals of the state and the royal family. The emperors and aristocracy used to keep close relations with Buddhist masters. However, the Buddhist monasteries always used to be kept under the administrative control of the emperor. During the Tang regime the number of monks

and nuns were kept down in size and the state introduced a clerical examination in order to ensure the quality of new entrants to the monastery.

Contact with India was at its best during this time. There was a spate of Chinese pilgrims to the Indian Buddhist centres. Hsuan-tsang (Huan-shang) was the most noted of them. He travelled in India during 629-645, learnt Sanskrit and later translated many texts he had carried back with him. All the different Mahayana versions had reached China. Hsuan-tsang himself spread the Yogachara doctrine. Several original Chinese doctrines also came into being: (i) Ching-tu (Pure land school), (ii) Pan Chiao, (iii) Tien-tai and (iv) Chan (became Zen when improvised by Japanese masters). Most of these Chinese sects recorded their history in chronological order of their patriarchs. In 729 an edict required all members of the Buddhist clergy to be registered. There was a great repression in 842-845 when 260,500 monks and nuns were forced to return to normal life. However, the importance of the large monasteries under famous masters remained unhindered and they continued enjoying the privileges of landed estates. The monastaries, in their turn, established religious societies for down-to-earth social work in the Mahayana tradition of charity. They established hospitals and dispensaries, gave aid to the poor and distributed food during famines, set up public utilities like roads, bath houses, built bridges, dug wells, etc. Buddhist festivals and processions, which were very popular, became a means of contact with ordinary people. The temple fares developed into regular markets for the people. With the discovery of printing the entire Buddhist scripture was printed by an imperial order. The wealth of the rich monasteries increased to such an extent that they started money lending, pawn-broking, and invested money in commercial ventures like water powered rolling mills and oil presses. They also hoarded a large quantity of precious metals in the form of religious objects and statues. Already in 715 AD the antagonised government had ordered confiscation of all copper and bronze articles.

With growing emphasis of Tang on the Confucian examination system, the antagonism with Buddhism was further enhanced. The grand finale came in 845 AD when emperor Wu-tsung ordered destruction of all Buddhist establishments and secularisation of all monks and nuns; all temple lands and other material possessions of the Sangha were to be confiscated. However, Buddhism was not prohibited as a religion to be practised by individuals. Within a few years the next emperor revoked these edicts and the Sangha started functioning again. But the decline of Buddhism in China had already started in an alien culture where the best intellects were in favour of Confucian examination system and not an autonomous monastery. However, Buddhism was far too well entrenched when this danger arose and hence its decline in China was a longdrawn gradual process.

In the remainder of this historical account I shall try to focus on the great achievements of ancient China in the field of human artistic and intellectual activities - literature, various art forms, science and technology. China's contributions to philosophy - indigenous Confuciarism and Taoism and creative additions to Buddhist Mahāyāna doctrines - have already been described at length. Some mentions of Chinese historical records have also been made. I may just add that these records, quite large in

number, not only relate to the ruling dynasties and the rulers, many of them deal with Buddhist institutions and masters, hierarchy of patriarchs of different sects etc. Some of the available old historical works also deal exclusively with the various tribes that were ultimately absorbed in the Chinese empire. Emperor Taizong had set up a historical society cum institute and appointed a Director of the organisation to supervise the compilation of history ultimately leading to the traditional form of writing history in a biographical style. In geography 'The Book of Rivers' - only known work compiled around 500 AD - was quite comprehensive. Chinese literature has a very old history starting in the second century BC. It is mainly classified as 'fu' (descriptive prose interspersed with verses) and 'yuefe' (folk songs and ballads). Later, during the Jin and the southern and northern dynasties works on literary criticism also appeared. Sui and Tang period is marked by a prolific spurt in literary works - surviving Tang poems number about 50,000. With direct patronage of the emperor dancing, acrobatics and music, together called yue, made unprecedented progress. The government made arrangements for training and staging performances. A large number of musical compositions found in Tun - Huang are the earliest extant musical scores of China. Temple buildings, to start with, followed Indian traditions but very soon the Chinese traditional architecture came to the fore. Frescoe paintings and sculpture work on Buddhist statues were also introduced by Indian experts in the Chinese grottoes. The Chinese artists and artisans, after learning the techniques, transcended the mere mechanical stylisation and infused new shades of beauty into their works by a creative fusion with their own ideas. The art of printing on silk and calligraphy are entirely indigenous and was developed to great heights. In fact calligraphy offered very popular official careers during the Tang days. Several hundred painters thrived during this period. The mural paintings and statues of Buddha in the grottoes and stone horses in the mausoleum of Taizong are very famous works of art to the connoisseurs around the world.

The technological achievements in agriculture, water management, metallurgy, metal works, road and bridge building, shipping etc. has been already described in appropriate historical order. I need to add that China was the first to invent the technology of paper making during the Western Han period and improved it further during the Eastern Han. The technique was transmitted to Europe from China during the late Tang period. The potentiality of this technology was completely fulfilled with the invention of block printing by China during the Tang regime leading to printing of many Buddhist canonical texts, as already mentioned. In the period of Warring States the Chinese discovered the use of lodestone for the north-south direction finding; they later evolved it into a proper compass somewhat after the Tang period. The technique of sericulture for silkworms and planting of mulberry trees were also originally introduced by the Chinese fairly early in their history. Gunpowder was first invented in the late Tang period and refined somewhat later.

Some of the early contributions to mathematics has been already mentioned. The Chinese learnt the use of the Pythagorus's theorem somewhat late in the 1st century BC. Zu Chongzhi (429-500 AD) worked out the ratio of the circumference to the

diameter of a circle (π) to the seventh decimal place, a feat about a thousand years ahead of the west. Mojing, written in the end of the warring states period, contains several concepts of physics - relative motion, relation between force and motion, basic principles of lever and pulley, rectilinear propagation of light and images produced by plane and spherical mirrors (basically the foundation of geometrical optics). At least two works on Alchemy, dating back to 100-350 AD, are available which contain several important chemical reactions. Chinese traditional medicine and medical treatment originated as early as the Spring and Autumn period. Many old compilations are available dealing with medicine, fever and diseases, principles of treatment and diagnosis, acupuncture and moxibustion, pharmacology and Materia Medica. Surgical methods were also known; Huo Tao belonging to the 2nd century AD was a leading name who, it is claimed, knew the use of anaesthesia. Emperor Taizong set up an Imperial Academy of Medicine divided into departments. 'Book of Fan' completed in 1st century BC is the earliest book on agricultural science and expounds methods of raising and processing quality seeds. Another book compiled in the Northern Wei period details method of cultivation on arid land, breeding of grain crops, rotation of crops by using green manure, techniques of grafting early maturing pear trees, propagating tree seedlings, castrating and fattening livestock and poultry and processing of many farm products. The contributions of ancient China to astronomy will complete this summary on science and technology and will be taken up separately in the next section of this article.

3 Astronomy in the ancient world

Instead of following a strictly chronological or countrywise presentation, I shall first introduce a few basic astronomical concepts in the interest of the uninitiated readers. The old civilisations have left such a wealth of astronomical informations and records of data that a minimum exposure to the basic concepts are needed as a prerequisite of appreciating and comprehending even their early contributions. Up to a certain point in antiquity each of the civilisations must have acquired and recorded many basic facts observed by inquisitive gazers of the sky without any help from or knowledge of similar observations and inferences made by others, geographically and politically quite well separated from them. Therefore, in spite of many overlaps and similarities that the experts notice now, it would be wrong to give exclusive credit for a specific contribution to any particular civilisation mainly on the ground of anteriority in the chronological history. Of course, it would be fair also to remember that as contacts between the different peoples evolved with time, and became quite intimate, at a certain point in the later history of these civilisations, indeed mutual exchanges did take place and one nation quickly picked up the prior knowledge of another thereby transforming its own researches into astronomy qualitatively and quantitatively. Even, while dealing with this later age, it sometimes becomes difficult, on the basis of available historical records, to conclude who learnt what from whom ! In my later

descriptions I shall comment on some examples of mutual exchanges and shall try to identify the recipient whenever such conclusions can be safely drawn.

3.1 Preliminaries

Records show conclusively that throughout the ancient world the experts knew how to determine very accurately the east-west, north-south directions. They must have used for this purpose what is now known as gnomon - a vertical stick thrust into the ground, verticality assured presumably by checking its parallelism with a plumb line (a heavy bob attached to a thread; it hangs vertically downwards when suspended from any support by the thread). Our Indian astronomers used to call this device a shanku. Fig. 1 (a) and (b) show a gnomon and its shadow cast on the ground at a

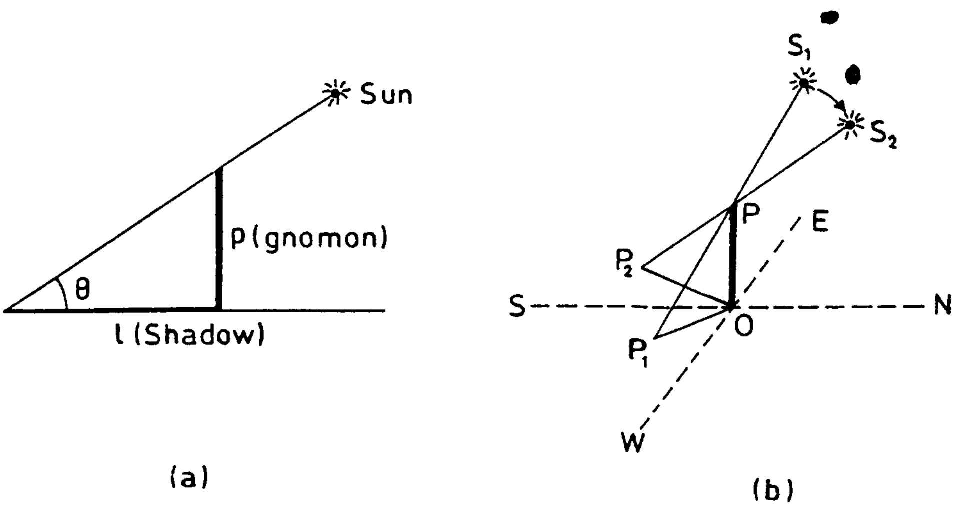


Fig. 1.

certain hour during the day. Clearly, the length of the shadow would be the shortest at noon when the sun is at its highest point in the sky. Instead of waiting for that precise moment, one can mark the position and length of the shadow somewhat before noontime [Fig. 1(b)]. After noontime the shadow will go to the other side of the noon shadow and will continue to grow. When it attains the length of the shadow measured earlier before noon, once again mark its position and length on the ground. When the angle between the lines of the two shadows (pre-noon and post-noon) is bisected by a line passing through the base of the gnomon, the bisector line marks the north-south direction. Bisection used to be achieved in the old days by first placing a rope connecting the end points of the two equal shadows and putting marks on the rope or cutting it at those two points. Finally the length of the rope between the two marks is

folded into half and half length of the rope is marked on the ground from the end point of one shadow along the line connecting it to the tip of the other shadow. Draw the line from the half-way marking to the base of the gnomon; it is the required bisector and is the north-south line as stated earlier. The perpendicular direction points east-west. The direction of sunrise determines east on the east-west line, and the direction to the left of east on the north-south line is north. The star gazers at night in the

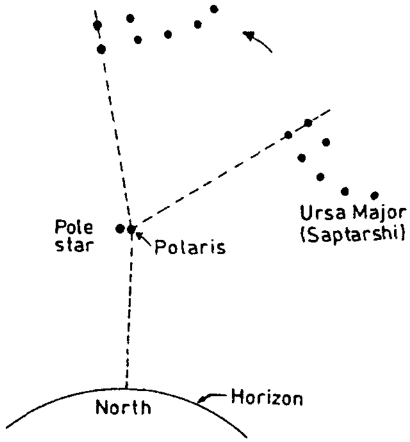


Fig. 2.

northern hemisphere of the earth (to which the old world civilisations belonged), looking upto the sky in the northern direction, can easily identify a constellation (a cluster of stars whose relative positions with respect to one another in the cluster remain fixed all the time) of seven stars (Fig.2) which is now called Ursa Major by professional astronomers and popularly known as the great bear or milk dipper in the English speaking countries; in India it is known as the Saptarshi from the ancient times and its seven individual stars have been given the names of seven well-known sages - Pulaha, Krotu, Atri, Pulastya, Angirā, Bashishtha and Marichi. A line joining the last three looks like a tail attached to one corner of an approximate square formed by the first four. Pulastya belongs to the corner of the square connected to the tail, while Pulaha and Krotu belong to the two corners on the other side of the tail. An imaginary line joining Pulaha and Krotu is shown in the figure. Even a casual observer of the sky notes that the constellation does not stay fixed in the sky; it rotates with time as shown by an arrow as night advances. The imaginary line, earlier mentioned, therefore also rotates to a new position. The point of intersection of the old and the new lines as shown in the figure, then marks the point (called Polaris) on the sky about which the constellation rotates. In the northern hemisphere there is a star very close to the Polaris point and it is called the pole star; its name in Indian astronomy is Dhruva tara. By imagining a line from the position of the observer to Polaris, one notices every night that the stars, the moon and other dots of light (the planets to

be introduced presently) all rotate throughout the night steadily about this line as the axis. Obviously, the stars close enough to Polaris remain visible through the night because their path on the sky are small circles that are completed above the horizon. The majority of the heavenly objects, sufficiently far from Polaris describe circles on the sky that are large enough so that only a part of the circle is contained on the celestial hemisphere of the observer. These objects follow their respective circles; they rise above the horizon and then set behind it during the night. The moon is one of them. It is known now that this apparent rotation of the whole sky is actually due to the rotation of the earth about an axis passing through its north and south poles perpendicular to its equatorial plane. The direction of the Polaris on the sky, as seen by an observer, is the direction of the earth's north pole connected by a line with its centre (Fig. 3). In high school geography the student learns that the angle subtended

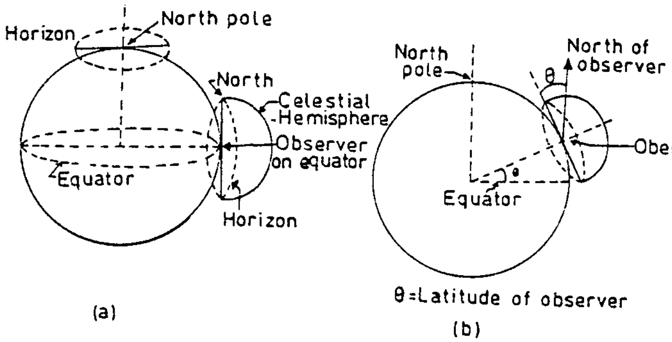


Fig. 3.

at the observer's position between the directions of the north point on the horizon and the direction of the polaris, is equal to the latitude of the place in degrees. A glance at the geometry presented in Fig. 3 will be persuasive on this point.

A vertical plane, perpendicular to the direction of the north, passing through the observer meets the celestial sphere on the circumference of a circle (a great circle of the said sphere) and obviously cuts the horizontal plane along the east-west direction. Imagine now rotating this vertical great circle about its diameter along east-west as the axis till it becomes perpendicular to the direction of the polaris. The new position of the great circle, perpendicular to the direction of the polaris, is clearly parallel to the equatorial plane of the earth and is called the celestial equatorial plane at the position of the observer. Note that it cuts the horizontal plane along the east-west direction because, while moving the vertical great circle to its new tilted position, a rotation was given about the said direction as axis, leaving it undisturbed. Since the daily rotation of the earth about its north-south polar axis, completed in 24 hours, appears as an apparent rotation of the entire celestial sphere about the direction of the polaris, completed in the same duration, the sun also exhibits this apparent daily

motion, and from what has been said just now, the sun's path along a great circle due to this motion will take it from the east point on the horizon across the sky to the west point (as we observe) during the day time ($\sim$ 12 hours) and from west point to the east point for the next 12 hours on the other side of the horizon so that it appears above the horizon again after 24 hours. Changes in these duration of daylight hours depending on the season and place will be dealt with somewhat later.

There is ample evidence that some of the early Greek, Indian and Chinese astronomers had indeed made an inference that the earth moves around its north-south axis once in a day and night (a full 'day' of 24 hours in astronomical parlance). Besides the apparent motion due to this cause, all ancient astronomers knew the most obvious fact that the moon's position relative to fixed stars gradually shifts from west to east when observed everyday at the time of the sunset. To be specific, on the new moon day the crescent shaped moon appears on the western horizon near the setting sun. Observed every subsequent evening at the sunset time, the moon is found to have enlarged its lighted area and moved near another star in the vicinity of its west-east path. Continuing this eastward migration and change of phase, it attains the full lighted face on the full moon 'day' (Purnimā) and rises on the eastern horizon (in opposition to the sun) at the time of sunset. The change in phase and the gradual migration of the moon with respect to the fixed stars continue; after completing a 360^0 circuit the moon appears in the vicinity of the 'first' fixed star where it was on the preceding new-moon 'day'. The time taken by the moon to do this is 27 'days', which means the moon describes on its track an arc of $13\frac{1}{3}^0 (= 800')$ each 'day'. The old world astronomers also noted that the sun too undergoes a west to east motion amongst the fixed stars along a path, called the ecliptic, and completes the course of 360^0 in a year during which 365 sunrises and sunsets take place. Thus the sun moves roughly 1^0 a 'day' and in 27 days it moves nearly 27^0. Thus, when the moon reappeares near the 'first' star, it is still behind the sun by 27^0. Since the moon gains about 12^0 over the sun every'day', the moon requires a little more than two additional days to be in 'residence' or 'conjuction' with the sun when we have the no-moon night (Amāvasyā). The new moon is visible in a day or two and from the previous new moon to this new moon, about $29\frac{1}{2}$ days, is reckoned as the duration of a lunar month.

The solar month is often defined as the duration in which the sun crosses every 30^0 of its path, thus completing the entire circuit in 12 months. If this definition is strictly followed, the summer months become slightly longer than the winter months; moreover, very often 30^0 of the path is described in a full number of days near 30 plus or minus a fraction of a day. While preparing civil calendars this inconvinence of having to deal with fractional number of days, was bypassed by different groups of astronomers with different prescriptions as will be detailed later.

Besides the sun and the moon, five more luminous objects, nearly the same apparent size as the stars, were identified with the distinctive property that they too move along orbits very close to the ecliptic. In the earliest days of astronomy all these five bodies, along with the sun and the moon, were called 'planets' (graha). At the present time we, of course, know that our earth together with the group of five -

Mercury, Venus, Mars, Jupiter and Saturn - are proper planets belonging to the sun and the moon is a satellite of the earth. Their apparent luminosity, including the moon's, is due to illumination of their surfaces by the sun. The paths of the moon and the 5 planets on the celestial sphere, as seen from the earth, is very close to the ecliptic ranging between 5^0 on either side of the latter's plane. One may immediately ask how did the ancient astronomers trace the ecliptic in the sky since no stars are visible when the sun is up. Present day experts surmise that they did it from different kinds of observations: (i) they were specialised in observing 'heliacal' rising of known stars. It technically means a star in the eastern horizon visible just before sunrise in a direction nearly coincident with the sun's. Observing systematically throughtout the year, a set of such stars lying close to the sun's path must have been found; (ii) lunar eclipses take place when the moon is exactly in opposition to the sun (sun, moon and earth all lying in the plane of the ecliptic) exactly 180^0 off from the latter with the earth in between. Stars that are observed in the close vicinity of the moon during its eclipses, therefore, lie near the ecliptic; (iii) Rarely they may have also identified the stars near the solar disc at the time of a total solar eclipse. The line joining all such stars, identified by the different methods, then yields the ecliptic, so called perhaps because of the role of eclipses in locating it. Ancient astronomers knew

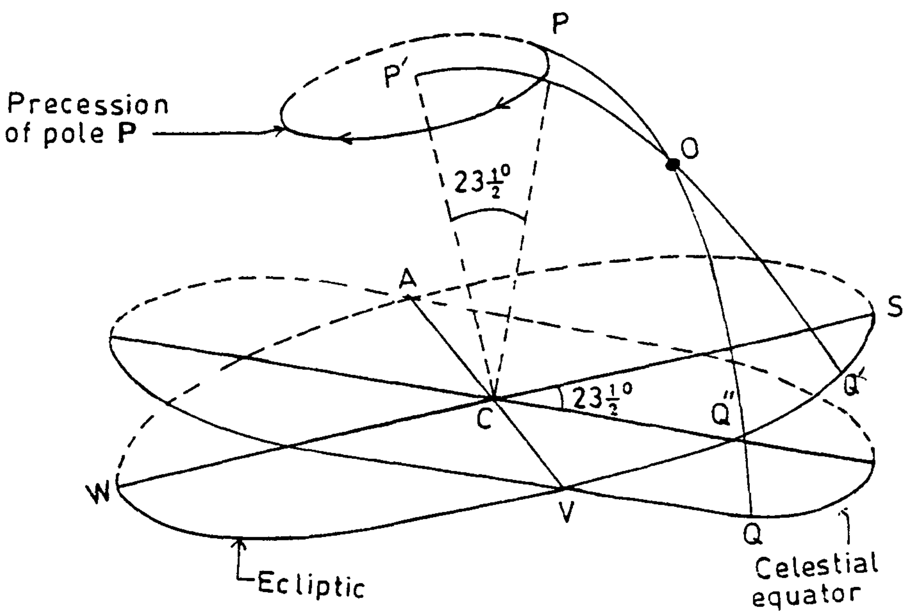


Fig. 4.

from experience that the sun's annual rotation round the ecliptic brings about the changes in the seasons. They had also observed that the celestial equatorial plane and

the plane of the ecliptic make an angle of $23\frac{1}{2}^0$ with each other and this inclination between the two is the prime cause why days and nights are generally of unequal lengths at all places off the earth's equator throughout the year with the exception of two special days - one in spring and one in autumn. On these two days the sun crosses the points of intersection of the ecliptic and the celestial equator (Fig. 4), called the equinoxial points. The point V, reached by the sun in spring (21 March), is called vernal equinox, and the pint A reached in autumn (23 September) is called autumnal equinox. On both these occasions the sun rises exactly in the east and the day and night are of equal length. From V the sun moves a little everyday along the ecliptic towards the point S (summer solstice); it may be noted from the diagram that the sun on the ecliptic gradually moves closer to the polaris, i.e. towards the north. The ancient astronomers made systematic observations on the direction of sunrise every morning and had noted this gradual northward migration of the sunrise point on the eastern horizon. In India they called this motion Uttarāyana (northerly course). At the summer solstice point S (22 June) the sun appears stationary for a few consecutive days and then it starts moving down the ecliptic, away from the polaris in the opposite direction on its southward course, called Dakshināyana. It reaches the autumnal equinox A on 23 September rising directly east and then further towards south from the exact east till the point W, the winter solstice, is reached on 22 December. From the point of extreme southward migratiin at sunrise on the winter solstice, it again commences on the northerly course completing the year at the vernal equinox.

In the days of ancient astronomy the relationship between the length of daylight hours and sun's position on the ecliptic, and consequent changes in seasons, were established by direct observations. A proper explanation can also be obtained by referring to Fig. 5. In (a) the position of the sun (S) on the summer solstice day has been schematically depicted. $E'E$ is the equatorial line (in fact a circle on the earth's sphere). The plane of the ecliptic, schematically represented by the line $T'T$ is inclined to $E'E$ by $23\frac{1}{2}^0$. P is the north pole and PCP' the axis of rotation of the earth. Clearly, the small circle on earth's surface, parallel to the great circle of the equator, and passing through T is the $23\frac{1}{2}^0N$ latitude line, i.e. the tropic of cancer. The sun S on the ecliptic is thus directly above the tropic of cancer. Imagine dividing the earth into two equal halves along QQ' (perpendicular to $T'T$); then the earth's half surface to the right of QQ' is lighted by the sun, whereas the other half to the left remains in darkness. Since the earth rotates about PCP' in the direction of the arrow above P, it is clear from the diagram that (i) all points from the arctic circle (angle $QCP = 23\frac{1}{2}^0$) through Q (the dashed curved line) always remains in sunlight when the earth completes its daily rotation; (ii) any point on the equatorial belt corresponding to $E'E$, however, spends equal time in light and darkness; (iii) points above the equator and up to the northern arctic circle spend a longer time in daylight than the time spent in darkness. The reverse situation prevails in the southern hemisphere. The longer days lead to continuous warming up of the earth's surface and the atmosphere, leading to summer conditions in the northern hemisphere. The situation at autumnal equinox is represented in Fig. 5 (b) on its right hand side. On this day the sun (S) is

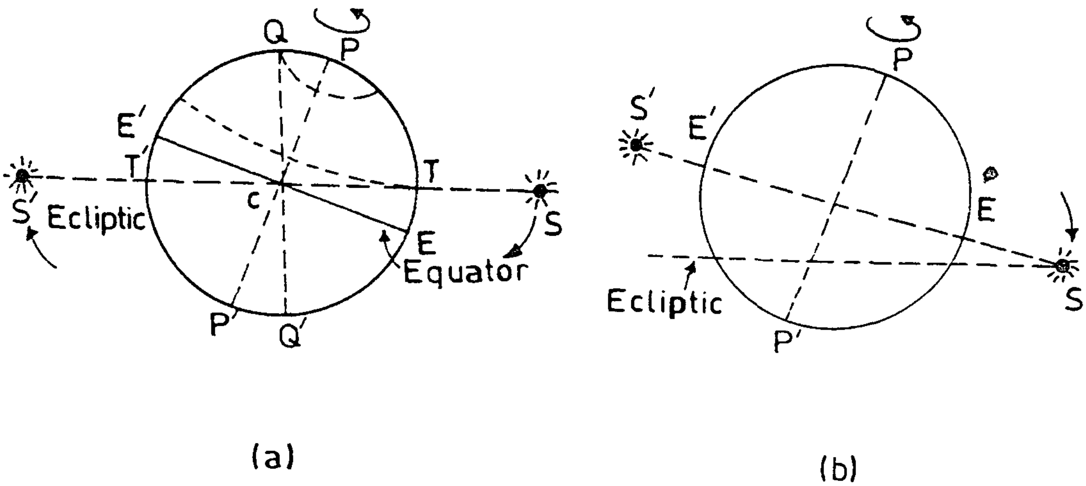


Fig. 5.

at the crossing point of the equator and ecliptic as shown. Therefore, it lights up the half surface of earth to the right of PCP'. The earth's daily rotation about PCP', therefore, brings every point on its surface to equal durations of light and darkness. The situation at winter solstice and vernal equinox can be understood in a similar manner, keeping in mind that the sun is at S' as shown in Fig. 5(a) and (b) on their left hand side i.e. on the far-side of the inclined polar axis.

Following the renaissance in Europe, Copernicus (1473-1543), a Polish astronomer who taught in Italy, propounded the heliocentric theory, published in 1543, which asserts that the earth and the other planets move around the sun. Galileo (1564-1642), the famous Italian physicist and astronomer, built an astronomical telescope to aid his observations of the sky. He directly demonstrated that the Jupiter has a number of satellites going round it - a miniature solar system revealed through the telescope. Johannes Kepler (1571-1630) studied the apparent movement of the planets and verified that the experimental data can be described accurately if they move on ellipses with the sun at one facus of the orbits. He formulated a set of laws of planetary motion one of which states that the line joining the sun with a planet sweeps out equal areas inside the elliptic orbit in equal intervals of time. I shall refer back to this law somewhat later.

Isaac Newton (1642-1727) built up a proper scientific theory by postulating the existence of a universal attractive force of gravitation between any two bodies having masses m_1 and m_2, separated by a distance r, the magnitude of the force being equal to $(Gm_1m_2)/r^2$ where G is the universal constant of gravitation. He gave a mathematical derivation of the motion of a planet due to its gravitational attraction with the sun, and proved that, in keeping with Kepler's assertion, the orbit is indeed

an ellipse with the sun at one focus. Orbits of the different planets are not coplanar; they make small angles with the earth's orbit (by definition, parallel to the plane of the ecliptic). The moon rotates around the earth under the gravitational attraction of the earth. Because of the small distance between the two, this attractive force is very much stronger than the total gravitational force on the moon due to the far away planets and the sun in spite of the larger masses of the sun and some of the other planets. The lunar orbit is also slightly inclined to the earth's orbit. Truly speaking, the motion of the sun, moon, and the five planets on the celestial sphere, experimentally studied by astronomers, are the relative motions of these bodies as observed from the earth. As long as we measure from an astronomical laboratory fixed on the earth's surface, we can observe only this relative motion and hence all the data acquired by old world astronomers, relating to these motions, still serve their purpose and utility. They are not falsified or rendered useless by the works of Copernicus, Galileo, Kepler and Newton.

I have mentioned earlier that, if the solar month is defined as the time taken by the sun to cross each successive 30^0 arc on the ecliptic then the summer months are longer than the winter months. Kepler's law on areal velocity of planets provides the correct explanation of the observation by ancient astronomers. Since the sun's apparent motion is due to the earth's actual motion in its orbit around the sun, it will be necessary and sufficient to find the time needed by the earth to cover 30^0 of its elliptic path. The earth is near the aphelion position on the ellipse with respect to the sun at the distant focus during summer time and at the perihelion position in winter when the sun is at the nearer focus. Here both summer and winter refer to the northern hemisphere, where the observations were made. Because aphelion distances on the ellipse are larger than the perihelion distances the area swept by the line joining the sun with an aphelion position of the earth through any angle will be larger than the area swept by the same line (shorter) connecting a perihelion position and describing an equal angle. Thus the duration in traversing a 30^0 arc on the elliptic path in summer is larger than in winter.

There are two more experimental observations by the old world astronomers for which they had no understanding: (i) the precession of the vernal equinox - small unidirectional shift of $50''$ per year along the ecliptic; (ii) the phenomenon of epicycles - an occasional reversal of the direction of motion of a planet (e.g. mars) as seen from the earth for a limited period and resumption of the usual easterly motion after a twist in the path. A proper explanation of these require a knowledge of the heliocentric picture and Newton's mathematical derivation, already referred to. I shall revert to these topics at an appropriate place.

As soon as the ancient astronomers noted the movement of the moon, some of them attributed a special correlationship between the fate of individuals, and even of entire nations, with the different positions of the moon as specified by the fixed stars. Astrological practices and forecasts thus grew up and became very popular amongst a set of wealthy people and, specially, the rulers. With the discovery of the movement of the sun and the planets too, an immense possibility opened up in con-

ceiving of special individual positions as well as an endless combination of positions. Imaginiation was let loose in relating these to human destiny in all sorts of ways. While modern rationalists decry the societies (particularly the Indian society) that are steeped in superstitions associated with astrological beliefs, impartial historians do not fail to observe that in the ancient world lucrative astrological practices provided the main incentive and impetus to extensive data gathering by priestly astronomers with continuously improved techniques and accuracy. Many of the modern progressive self-proclaimed scientifically oriented intellectuals, culturally brain washed by a host of western authors, parrot the greatness of the Hellenic Greeks in pioneering the developments of science and all rational enquiries. It may embarrass them to know that the Greeks, who learnt their first lesson in astronomy, as well as astrology, after coming into contact with the Chaldeans, were as much guided by the incentive of astrology as their Chaldean teachers were. In fact Greeks also wrote astrological treatises and even served as hired astrologers of wealthy Romans. As remarked earlier, this money-earning incentive kept up the astronomical data collection activities by the Greeks as well as the Chaldeans and led to important developments in astronomy between 500 BC and 200 AD, It would be vry unpalatable to the so-called progressive to know that in India, starting before the 5th Century BC ending with the Maurya peirod, astrological practices were decried as superstitious beliefs by leading preceptors. As typical proof of this little known fact M. N. Saha and a group of his specialist astronomer colleagues on the National Calendar Reforms Committee have cited ('Collected Works of M. N. Saha', vol. 3, ed. S. Chatterjee, Publisher: Saha Institute, distributors: Orient Longman) in their comprehensive report several emphatic statements by Lord Buddha and later by Kautilya in his Arthashāstra. In fact the said report attributes the near absence of proper astronomical developments in India between 500 BC and 200 AD to the stricutures on astrological practices by such eminent preceptors who had the rulers as their disciples.

Coming back to the urgency of preparing reliable charts of data on the variable positions of the sun, moon and the five planets, and later the fixed positions of the identifiable stars and constellations, it is to be noted first that two angular co-ordinates (i.e. arcs of great circles) are needed to specify any such position on the celestial sphere just as we need the latitude and longitude to specify the position of a point on the earth's surface. Astronomers of the old world used several different schemes for their purpose which I now proceed to describe. We need a great circle on the celestial sphere and a specified point on it as the origin of co-ordinates. Already we are familiar with two such great circles (Fig. 4) - the celestial equator with its pole P and the ecliptic with its pole P'. Since the two great circles intersect at the equinoxial points, one can conveniently choose the vernal equinox as the origin and then use either of the two to measure one of the co-ordinates from the origin along its arc. To specify both the angular co-ordinates of a heavenly body on the celestial sphere at O, using the celestial equator, one then needs to draw the meridional line (part of a great circle) from P, passing through O and perpendicular to the equatorial line at Q. The arcs VQ and OQ equivalent to the longitude and latitude of a point on earth are called

respectively the right ascension and declination and they specify the two angle co-ordinates of O. The other alternative is to use the ecliptic and the arc on it measured from V as one of the co-ordinates. To specify both, as before, draw the meridional line from P' through O perpendicular to the ecliptic at Q'. Then VQ' and OQ' provide the two angle co-ordinates, and are called celestial longitude and latitude respectively. Another peculiar practice, first introduced by the Greek astronomer Hipparchus and later extensively followed by the Indian Siddhāntic school, uses the arcs VQ'' and OQ'' where Q'' is the point on the ecliptic through which the meridional line POQ passes. Clearly, $POQ''Q$ is not perpendicular to the ecliptic. These two peculiar co-ordinates are now-a-days called the polar longitude and latitude respectively. Our Siddhānta astronomers called them Dhruvaka and Vikshepa.

Eclipses have been mentioned several times. A few preliminaries on them will now be stated. the phenomena were known everywhere in the old world. Direct observations had led to the correct conclusion that lunar eclipses take place when the sun and the moon are in opposition (full-moon or Purnimā night) with the earth in between. If the moon is on the same plane with the earth and the sun i.e. if it is on the ecliptic then the earth's shadow can completely cover the moon causing a lunar eclipse. Just because the Moon's orbit is slightly inclined to the ecliptic, it does not come on the ecliptic every Purnimā night. That explains why lunar eclipses do not take place at every full moon. The Moon's orbit and the ecliptic intersect at two points which Indian astronomers call Rāhu and Ketu. According to earlier remarks, a lunar eclipse can take place only when the moon is at either of these points at full moon. Indian astronomers, therefore, picturesquely imagined Rāhu and Ketu as two demons one of whom, during the eclipse, swallows up the moon and then passes it out as the demons only have their heads on their neck, severed from the rest of the body by vengeful gods. Similarly, solar eclipses take place when the sun and the moon are in conjunction, as seen from the earth, and all three are in the plane of the ecliptic. The moon necessarily lies between the earth and the sun, and hides the latter from our view by obstructing the sun's rays coming towards the earth. Since the moon is much smaller than the sun, at times it can only partially hide the sun. Under favourable circumstances, depending on the moon's distance from the earth, it is able to produce a total eclipse of the sun. Once again, a solar eclipse, total or partial, can take place only when the moon is at either Rāhu or Ketu, and not during all Amāvasyas (no-moon night).

4 Contributions of different countries/nations

4.1 Egypt

Egyptians had a calendar of 360 days divided into 12 months of 30 days each. They knew from experience that, on a particular day in the year, the brightest star Sirius, which they called Sothi, had a helical rising with the sun. The rest of the year it gets out of phase with the sun and again comes back to the same position after 365

sunrises. Incidentally, the Nile flood used to arrive near their old capital city on the same day. They started their year on that specific day with the month of Thoth and added 5 extra days at the end of their annual calendar of 360 days. The added days were called Epagomenai' the days of festivity, which were not counted for any civil or religious purposes. The observant priests who used to keep the records from their great temples had indeed noticed that, from year to year, Sothi takes a little more than 365 days to come back to the horizon at sunrise; in fact they found that two consecutive exact helical risings take place every four years provided one extra day is reckoned in the fourth year. Thus, a solar year of $365\frac{1}{4}$ days was within the knowledge of Egyptian experts. Unfortunately, during the Pharaonic days and even after the Greek Ptolemy dynasty came to rule from Alexandria, no correction was introduced by including an extra day every fourth year. To complete the specific Egyptian achievements, I must also mention that the bases of the great pyramids built around 2400 BC were perfectly aligned east-west, north-south. It is, therefore, clear that they knew the use of gnomons.

4.2 Sumeria/Babylonia/Chaldea

The ancient Sumerians and later the Babylonians and the Chaldeans were better familar with astronomical observations and accurate data gathering. Every city state of theirs used to have a multi-storeyed temple called Ziggurat for their city god. The temple priests were specialised in astronomical observations from suitable platforms on the different floors of the tall temples. Typical boundary stone tablets have been found in Babylon with astronomical records which include sculptured figures and symbols of sun, moon, planets and constellations, lunar positions etc. Two astronomical texts called 'MulApin' compiled around 700 BC have been found which summarise the astronomical knowledge of the time. The known fixed stars are divided into three groups, the central one covering about 30^0 width of the equatorial belt. Facts known about the sun, moon, the seasons, lengths of shadow etc. are also available. The description is very much on a rational basis. The Chaldean astronomers at that time could identify the north pole, and had traced the celestial equator on the sky. A knowledge of star groups near the ecliptic was obtained as early as 1300 BC and are portrayed in boundary stone tablets. Ecliptic is explicitly mentioned in a text belonging to 419 BC. Its use as a reference plane must have started before 550 BC. Early Babylonian astronomers observed that the bright stars Regulus (Maghā), Spica (Chitrā), the group pleiades (Krittikā) and familar stars alpha-librae and alpha-scorpii were almost on the ecliptic and they must have traced the ecliptic by joining these stars. The Babylonian astronomers knew 27 or 28 stars that the moon passes by during consecutive nights in a lunar month. They named the lunar days after these stars and subsequently shortened the list by introducing the 12 signs of the Zodiac each covering 30^0 of the zodiacal belt containing the ecliptic and the orbits of the moon and the planets. Each such section of the zodiac was then named by a star group contained in it. these names were used in Indian Astronomy as well at a later

date translating them into Sanskrit - Mesh, Vrisha, Mithuna etc. The present English names - Aries, Torus etc. - also replicate the Babylonian names.

The Chaldean astronomers recorded the celestial latitude and longitude of the sun and the moon over many years. For the planets they determined only the celestial longitude. From about 500 BC they prepared lunar ephimeris based on calculations by methods obviously derived with the help of their experimental data. although they had no knowledge of spherical geometry and trigonometry, they perfected the concepts of measuring positions by two angles and applied arithmetical methods to interpolate their data, whenever necessary, between measured maximum and minimum values of astronomical entities. They had knowledge of both the lunar month and the solar year and took great pains in devising methods to bring the shorter lunar year ($29\frac{1}{2} \times 12 =$ 354 days) into concordance with the longer solar year. After making many different experiments they finalised a luni-solar adjustment in a cycle of 19 solar years by adding an extra lunar month of 30 days (called the intercalary month) to the lunar year of 354 days at the end of the 1st, 4th, 7th, 9th, 12th, 15th and 18th years. These seven intercalary months were considered as mere appendages and of no use for performing any religious or civil ceremonies. The adjustment is briefly explained below:

19 solar years = $1939\frac{3}{4}$ days @ $365\frac{1}{4}$ days per year

19 lunar years + 7 intercalary months = 6939.69 days

This adjustment thus leaves an error of only 0.06 day in a length of 19 years. In the same spirit the Babylonian astronomers established (in 383 BC) a cycle of 18 years $10\frac{1}{3}$ days based on their extensive data on eclipses gathered over centuries; it is called the Babylonian/Chaldean Saros. The sequence of lunar and solar eclipses, their exact intervals of occurrence, as listed in the Saros are repeated during each consecutive cycle. They also had other approximate methods of predicting the date and time of eclipses.

The finest contribution of the Chaldeans was the observation that the vernal equinox (Vin Fig. 4) does not stay fixed on the ecliptic. They did not know the real explanation but established experimentally that the observed celestial longitude VQ of a fixed star, when compared with the same data on their old records belonging to many years (~ a century or more) earlier showed a considerable difference. Around 400 BC, the Babylonian astronomer Kidinnu found that the vernal equinox lies in the star group Aries at his time, whereas, according to the very ancient (~ 2300 BC) records of Uhr, the vernal equinox was then located in the Pleiades. It is now known that the vernal equinox shifts slowly to the west along the ecliptic through roughly $50''$ in a year (i.e. 1^0 in 72 years), and the phenomenon is known as the precession of equinox. It is unidirectional and cummulative and hence quite important in astronomy. One has to remember that the day and nights are of equal length when the sum is at vernal equinox. If the year (like in ancient India) commences from this position of the sun, then it should be deemed to be completed when the sum again comes back to the vernal equinox; but since it is $50''$ to the west from its previous location on the ecliptic, the year reckoned in this way (which is the correct astronomical year from the point

of view of seasons) will be slightly shorter than the time taken by the sun to describe full 360^0 circuit of the ecliptic. From vernal equinox and back to it, the tropical year consists of 365.2422 days while the full 360^0 circuit defines the sidereal year of 365.2563 days. If the precession of the equinox is ignored in reckoning the commencement of a year, the actual seasons will lose their correlations with the corresponding months of the calendar as years roll by. Here I choose only to add the real cause of the precession of equinox as has been clarified by Newton's derivation fo planetary motion and the mathematics of rigid body rotation (Eulerian motion). Since the earth is not a perfect sphere and has a shorter radius in the north-south direction compared to its radius in the equatorial plane, its moment of inertia along any axis perpendicular to CP (Fig. 4) in the equatorial plane is slightly different from the moment of inertia about the polar axis CP. The earth rotates about CP and simultaneously moves along its elliptic orbit under the action of the gravitational attraction of the sun. According to the mathematics of Eulerian rotation of a rigid body about a symmetry axis (CP in this case), the rotation axis undergoes a slow precession about an axis fixed in space (direction CP′ in the present cae). The uninitiated reader will be convinced if he recalls the motion of a top about its axis of symmetry when the latter is slightly inclined to the fixed vertical direction; it is a familar sight that the rotation axis of the top itself slowly rotates ('precesses') about the vertical. Referring to Fig. 4, the tip of the axis CP precesses around the circular dashed line around CP′. As soon as CP moves through a small angle, the celestial equatorial plane which is required to be perpendicular to the new position of the polar axis, also necessarily changes its orientation. As a result its intersection with the fixed ecliptic changes and hence the vernal equinox, which is one of the points of intersection, also shifts along the ecliptic.

The Chaldeans are also the originators of the seven-day week, which was introduced only to break the monotony of a month into smaller cycles with a provision of one or two no-work days in each week. This was done at a time when they still treated the seven so-called 'planets' as guardian deities with occult powers on the destiny of individual human beings, society and the state. The seven days were named after the seven planetary gods as is only too obvious from their Indian names - Rabi, Som etc. - that we are familiar with. In India these names first occur in an inscription of emperor Budhagupta of the Gupta dynasty dated 484 AD.

4.3 The Greeks

Some of the early credits in astronomical knowledge attributed to the Greeks by their admirers in the west do not really stand present-day scrutiny by knowledgeable experts. Once again I have to cite the authority of M. N. Saha and his colleagues, quoted earlier. The unfounded claims relating to very early dates are listed here: (i) knowledge of the 18 years 10 $\frac{1}{3}$ days cycle of the occurrence of eclipses has been ascribed to Thales of Miletus (624-548 BC), the first rational scientist of the civilised world as certified by western authors. (It is well established on the basis of available records that the Saros, mentioned earlier, was first introduced by the Babylonians

around 400 BC); (ii) Aneximander (610-545) is said to have used the gnomon. (But this certainly was not original. Chaldeans and the Vedic people of India used it much earlier in the history of astronomy); (iii) Cleostratos was credited by later Greeks to have introduced in 530 BC the zodiac and an eight year luni-solar adjustment with a proper number of intercalaries. (If true, it is definite he merely transmitted the Babylonian knowledge on both these subjects); (iv) Meton was said to have originated in 432 BC the 19 year cycle with 7 intercalaries. (Conclusive researches into old records place the first use of this system by Greeks in the year 342 BC, the Babylonians having originated it in 383 BC); (v) Greek authors of later days have claimed that members of the school established by Pythagorus (~ 500 BC), specialised in geometry, astronomy and mathematics, knew that the earth and the planets were spherical bodies. (In spite of the fame of Pythagorus in geometry, his main theme of teaching in his school was eastern mysticism, surely picked up during his earlier travels in the near east. Experts fail to find any records as to when and on what grounds members of his school contributed any new fact or idea in astronomy).

Historically speaking, Greek genius first flowered in geometry. Starting with Pythagorus, developments took place in the hands of scholars like Hippochrates, Democritus of Abdera, and above all Plato (428-348 BC) and his junior disciples. All this geometrical knowledge was compiled by Euclid (~ 280 BC) at the Museum in Alexandria. During the heydays of the Persian empire the inquisitive Greeks had already been travelling in the near east in quest of knowledge in astronomy and other fields that had accumulated under the then superior and older civilisations of Egypt and Babylon. After Alexander's conquest, this intellectual contact received a greater impetus and was further promoted by the school in Alexandria. The Greeks learnt very fast from the Chaldeans and there resulted an era (340 BC - 150 AD) rich in the contributions by the Greeks and their teachers, the Chaldeans. After this period the Chaldeans gradually faded away but the Greek dominance in the field continued. These are the days when Heraclides, it is claimed, propounded that the earth rotates about is own axis; Anaxagorus, having seen a meteorite, conjectured that the moon is also composed of similar rocks and it is lighted by the sun; and what is most important, Aristarchus is said to have propounded the heliocentric picture - the earth, in addition to its rotation about an axis, also moves around the sun. However, it is also noticeable that great Greek astronomers (a few will be mentioned presently), following Aristarchus, were not aware of the claims that are attributed to him. Western civilisation and astronomers elsewhere, had to wait till Copernicus braved against the fear of persecution by the Christian Church, and published his heliocentric theory.

In the latest era of Greek glory in astronomy one has to recall the contributions of Eratosthenes, stationed in Alexandria, in measuring the diameter of the earth to a great accuracy, as has been earlier mentioned. Archimedes is credited with the invention of a 'planetarium' - a revolving spherical dome with internal mechanisms to imitate the motions of the seven 'planets' on the surface of the dome. He also attempted to find the actual distances of the 'planets' and order them on the basis of their distances from the earth: moon, mercury, venus, sun, mars, jupiter and sat-

urn. Note that the position of the sun in this list reveals that the scientist had no inkling of the planets resolving around a distant sun. The greatest name in this age is that of Hipparchus who was the curator in an astronomical observatory on the island of Rhodes (161-127 BC). His precise experimental observations established the precession of the equinox very conclusively, although within his limited life time of observations he could not independently assert that it is unidirectional. It is definite he was not aware of Kidinnu's work and observed quite independently that the position of Spicā (Chitrā) had shifted by 2^0 from the autumnal equinox point where it was according to data taken by Timocharis at Alexandria (280 BC). He gave a value of $51\frac{1}{2}''$ per year for the westward precession of the equinox. This amounts to $1^0 24'$ in a century and predicts that the vernal equinox will complete one full turn (360^0) around the ecliptic in about 26,000 years. Hipparchus had contacts with his contemporaries in Alexandria; through them Claudius Ptolemy who worked in the famous museum during 128-151 AD inherited many of the valuable instrumental innovations of Hipparchus and his elaborate catalogue on the positions of 850 stars. Ptolemy reproduced these data in his famous book Syntaxis and also made use of them in his book on astrology called Tetrabiblos. The instruments described by Ptolemy in his book are mostly adaptations from Hipparchus' - only the mural quadrant was Ptolemy's own. Although in cataloguing the stars, Hipparchus made the same angle measurements as done by the Chaldeans many centuries ahead of him, he had improved the accuracy by dividing the circles of his instruments accurately in 360 equal subdivisions each of 1^0. He listed most of his data on stellar positions in polar longitudes and latitudes and a few (67) in right ascension and declination. After the discovery of precession of the equinox he mostly used celestial longitude-latitude; these were also used by the Chaldeans about a century earlier. He had some knowledge of plane and spherical trigonometry and he was the first astronomer to use the double chord (Fig. 6) $2R\sin\theta$. Extensive tables were prepared for different values of the angle θ and radius R. Ptolemy improved these values in his book. More on this when I take up Indian contributions to astronomy. Menelaos, a Greek astronomer, developed spherical trigonometry (98 AD) and his results were later used by Ptolemy and Indian astronomers. These developments were much extended by the Arab astronomer al-Bettani. Besides Ptolemy's book which educated several generations of astronomers in different countries, the famous Alexandrian astronomer also emphasised the precession of the equinox; however, the value derived by him ($36''$ per year) by comparing stellar positions measured by him with the corresponding data in Hipparchus' catalogues was very much in error. Ptolemy's efforts at solving the problem of epicycles by applying geometrical methods were also unsuccessful and patently misconceived. The phenomenon of epicycles, observed by many astronomers has already been described. Before Ptolemy some of the Greek astronomers tried to construct an explanation by geometrical methods. Basically this method, extended by Ptolemy, is based on circular planetary orbits placed on or inside yet other bigger circles; Ptolemy invented a complicated arrangement of 40 such circles and claimed that he has explained the complicated planetary paths exhibiting occasional twists (the epicycles). This expla-

nation is however, wrong. The correct explanation, as stated earlier, is based on the planetary orbits around the sun and is very simple. In Fig. 7 reproduced from the

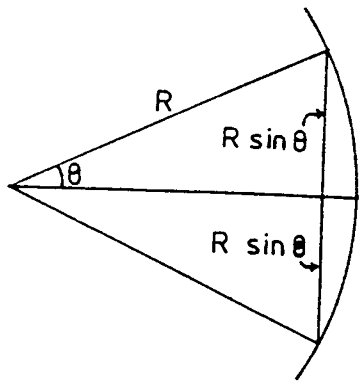


Fig. 6.

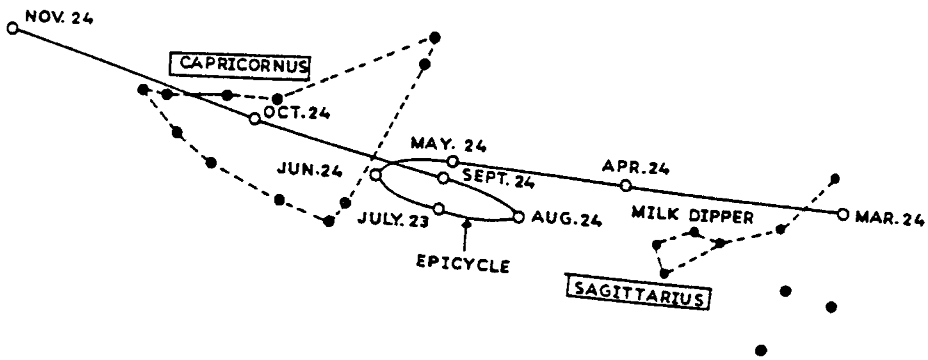


Fig. 7. The path of Mars among the stars in 1939

works of M. N. Saha quoted before, a typical epicycle as actually observed on the path of mars has been shown. The schematic diagram in Fig. 8, taken from the same source book, explains the phenomenon. Several consecutive positions of the earth and mars (outer orbit, farther away from the sun) are shown by black dots. The angular direction of mars on the sky, as seen from the earth, at any given instant is obtained by joining the two corresponding dots on the two orbits as shown in the figure. The numbers 1,2,3 ... on the extreme right denote consecutive positions of mars on the sky.

Because of the different angular velocities of the earth and mars in their respective orbits, it is seen that lines 4,5 drawn after the position 3 are in the reverse direction; finally after completion of a loop, the earlier direction is resumed at 6 and 7. After Ptolemy, Theon and Paulus - both working at Alexandria about 370 AD - are

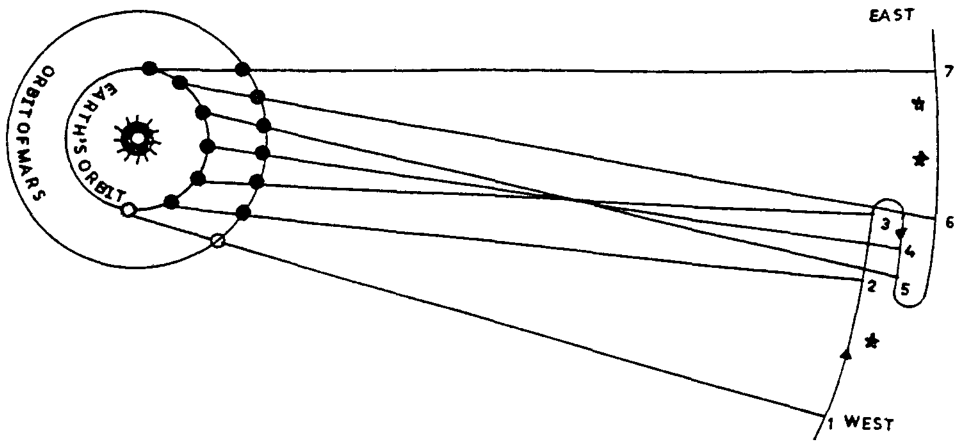


Fig. 8.

worth mentioning. Theon made a wrong speculation that the shift of vernal equinox due to precession undergoes an oscillation (called 'trepidation' theory). It is actually cummulative and unidirectional. Paulus wrote an introductory treatise on astrology.

4.4 Chinese

Ancient Chinese contributions in astronomy are in a wealth of data records and of developments in instruments. Some of these, as available to me from recent Chinese publications, are listed below: (i) a simple armillary sphere, an instrument for determining the positions of heavenly bodies was invented in 400 BC; (ii) in the days of Emperor Han Xuandi (73-48 BC) Gen Shou Chang built a celestial globe and later a water operated version was developed by Zhang Heng (78-139 AD); (iii) Shi's star catalogue (4th Century BC) preserves all the ancient observational data on the positions of stars; (iv) very clear records of lunar and solar eclipses and on novae have been found in oracle inscriptions on bones and tortoise shells; (v) Han dynasty books (Hou Han Shu) dated about 2000 years from now contain the wrold's earliest records on meteoric showers (687 BC), sunspots (28 BC) and supernovae (185 AD); (vi) China has detailed records of 29 appearances of the Halley's coment, of 90 novae and supernovae, and a number of intense sunspot activities compiled over many centuries;

(vii) during the Spring and Autumn period (770-476 BC) Chinese astronomers determined the length of the year as $365\frac{1}{4}$ days and adopted (perhaps independently of the Chaldeans) a luni-solar adjustment of 19 years with 7 intercalary months; (viii) the first Chinese calendar was introduced between 221 and 206 BC. (ix) Wang Chang's (27-97 AD) 'Lun Hang' claims that lunar and solar eclipses occur at calculable intervals and that lightining and thunder are natural phenomena; (x) the Chinese had also gradually identified over many years 27/28 asterisms (Indian nakshatras) like the Chaldeans, given them names; they had also shortened these to the 12 signs of the zodiac. The Chinese used the word Hsiu to denote the asterisms.

4.5 Rome

Except for a couple of official edicts for introducing calendars, the Roman contribution to astronomy in the ancient world is nil. However, the last of their two calendars (Gregorian) is now almost universally used all over the world for civil and official purposes. Hence I devote a little space to it. The old Roman calendar had ten months starting from what is now the month of March. The month names Spetember to December clearly identify them as the 7th to the 10th months. The equivalent of January and February were added at a later stage. The 12 months from then on consisted of consevutive pairs of 29 and 30 days. To bring this calendar into concordance with the proper solar months, 22 to 23 days used to be added to the last month every two years by the decree of a religious Pontiff. After Julius Caesar went to Egypt, he was impressed with the Egyptian calendar and learnt from the Ptolemaic school that a year really had $365\frac{1}{4}$ days. He took an Egyptian astronomer with him to Rome and, with his advice, introduced what is now known as the Julian calendar by a decree. It contained 12 months occurring in pairs of 31 and 30 days which counts upto a total of 366 days. Hence one day was taken away from February reducing it to 29 days. At the same time the great dictator wanted to have the fifth (counted from March) month Quintilus of the old calendar named 'July' after him. He also introduced the system of leap years, namely, a year number divisible by 4 was to have one extra day in February in order to make up for the $\frac{1}{4}$ day left out in each year. The next ruler of Rome, Augustus, also wished to leave his own imprint on the Roman calendar. He named the month following July as August after his own name and, in order not to be reckoned inferior to his predecessor, his month was also decreed to have 31 days. The additional day thus introduced was, once again, taken away from February reducing it to 28 days in a normal year and 29 days in a leap year. However, it became known many centuries later that the year was slightly shorter than $365\frac{1}{4}$ days. By the time of Pope Gregory XIII (1577 AD), the accumulated error was calculated to be 9 days. After consulting many astronomers the Pope decreed that out of the century years 100, 200 etc. those not exactly divisible by 4 after supressing the last two zeros, are to be counted as a normal year of 365 days thus depriving three of them of the leap year status in every 4 centuries. Thus the year 400, 800 etc. are leap years but 100, 200, 300, 500 etc. are not. The resultant calendar was called the Gregorian calendar and it

amounts to a mean year length of 365.2425 days. The residual error still left amounts to 3 days in 10,000 years. The accumulated error upto 1582 AD was corrected by a decree of the Pope by advancing the dates by 9 days.

4.6 India

Old history of Indian astronomical work is usually divided into three periods: the Vedic period (antiquity to 1350 BC), Vedānga period (1350 BC - 400 AD) and Siddhānta Jyotish period (400 AD - 1200 AD).

(a) Vedic period

Rigveda contains several hymns that speak of a year of 12 months, of 360 days and of 3 seasons (the chaturmāsyā system). The Vedic savants must have realised later that 360 days do not correctly encompass either a solar year, or a lunar year. There is thus a reference in one hymn to an intercalary month at the end of a year, thereby indicating the adoption of a luni-solar system. One particular verse has been interpreted by Lokamānya Tilak as a pointer to a luni-solar adjustment by adding 12 days to a lunar year of 354 days to make up its shortfall from a solar year of 366 days. Several references to nakshatras like Maghā (Aghā), Phalguni (Arjuni), Chitra, Tisyā (Pushyā) are found in the Rigveda but it is not clear whether in those early days they had any fair idea about the lunar mansions or the lunar zodiac.

The Yajurveda gives the names of the 12 months, the names of 27/28 lunar mansions (nakshatras) with their presiding deities and talks of uttarāyana and dakshināyana of the sun, The nakshatra Abhijit sometimes used to be omitted from the list of 28 to make the number of lunar mansions equal to 27. Taittiriya Sanghitā gives the names of the months in pairs, each pair consistuting a season: Madhu and and Madhava (spring), Shukra and Shuchi (summer), Nabha and Nabhasyā (rains), Isha and Urjā (autumn), Sahas and Sahasyā (hemanta), Tapas and Tapasyā (winter). The lunar month names - Chaitra, Vaishakh etc. prevalent now are found in the later Vedic literature. Experts believe that during the time of the Yajurveda, Indian astronomers must have found some method of observation for fixing the four cardinal points (the solstices and equinoxes) on the ecliptic and from such observations they had concluded that the year length is 366 days. In particular, Yajurveda speaks at places about uttarāyana of the sun from the winter solstice to the summer solstice, dakshināyana from the summer solstice to the winter solstice and also mentions the Vishuvan-an equinoxial point. There are evidences of year long daily obserations of the direction of sunrise. These observations must have clarified their ideas about the ayanas and the cardinal points. There is a mention of a device that resembles the gnomon in Aitareya Brāhmana attached to the Rigveda. They defined the beginning of the month Mādhava to coincide with the sun's position at the vernal equinox. The commencement of Madhu month was taken 30-31 days earlier. Giving an average of $30\frac{1}{2}$ days (because of alternating 30 and 31) to a month, they arrived at the figure of 366 days for the length of a year. The list of nakshatras given by Yajurveda and the epic Mahābhārata starts with Krittikā (the star group pleiades). This is also con-

firmed in one verse of Shatapatha Brāhmana. Most probably this implies that vernal equinox was close to Krittikā when the nakshatra enumeration started. The same list, as given in the Siddhānta Jyotish period starts with the Ashvini nakshatra when the vernal equinox point had shifted to the star Zeta-piscium lying near the beginning of Ashvini and the end of Revati. These facts clearly establish the precession of equinox over the intervening period.

The lunar month names occur in Taittirya Sanghita and also in Yajurveda. The month name was given in accordance with the name of the nakshatra where the moon resides during the Purnima night. Thus Phālguni Paurnamāsi is the completion of the month of Phālgun when the moon is near the Uttara-Phālguni nakshatra. The lunar year used to begin usually with the month of Chaitra, related to the Chitrā nakshatra and sometime with Vaishākha (derived from the nakshatra Vishākā). These month names are still prevalent in India and hence I need not to go through the entire list.

I have earlier mentioned that the moon gains 12^0 over the sun in a 'day'. In Indian astronomy each 'tithi' is acordingly defined to be completed when the moon is ahead of the sun by multiples of 12^0. The waxing moon thus marks out 15 consecutive tithis - pratipada, dvityā, trityā etc. ending with purnimā. In the same way the waning moon also marks out 15 more tithis, with identical names, and terminating with amāvasyā. The average duration of a tithi is about 23.62 hours, actual values varying between 20 and 26.8 hours on acount of the non-uniform lunar motion. Tithis are referred to in Yajurveda and some Brāhmanas, and its definition in the Vedic age is obtained from Aitareya Brāhmana: in the shukla paksha the tithi is to be reckoned from moon set to moon set, while in Krishanapaksha they extend from moon rise to moon rise. The more precise definition in terms of angles is from the days of Siddhānta Jyotish.

(b) Vedānga period

Besides the available sutras (aphorisms) of Vedānga jyotish, the epics (particularly the Mahābhārata), some Jain astronomical texts, and two other works called Jyotisha Karanda and Kalālokaprakāsha belonging to this period provide a lot of information. Measurements of the subdivisions of a day was improved by means of continuous observations of gnomon shadows and use of a new instrumental device later called clepsydra. The major emphasis was on calculational methods combined with some observations, for the correct determination of the nakshatras and the tithis. Precise definitions of the nakshatras and tithis were given and the general spirit was to reduce errors by considering the mean motion of the sun and the moon averaged over a large number of years of observation, namely a yuga consisting of 5 years. There is no evidence of studying planetary motion in the Vedānga period, nor of any systematic programme of day-do-day observations on the sun and the moon. The general principles of calculation were based on the following initial pieces of data: one yuga of 5 years = 1830 days @ 366 days in a year; a year comprises 12 lunar months plus 12 days, hence in 5 years one has 60 lunar months and 60 days. Each lunar month has 30 tithis, and adding 60 more tithis for 60 days, one had a total of 1860 tithis in a yuga. The nakshtra month is the time taken by the moon to complete a circuit past 27 nakshatras and come back to the same nakshtra. I have earlier stated that this takes

about 27 days. Thus 1 yuga = 1830 days = 1830/27 nakshatra months $\approx$ 67 nakshatra months (very approxinate). Assigning 27 nakshatras to a month, one then obtains $67 \times 27 = 1809$ nakshatras in a yuga (not equl to 1830 because of the approximation sated above). In Vedānga jyotish, therefore, out of the 62 lunar months in a yuga two are treated as intercalary months to obtain proper luni-solar adjustment with 60 solar months. thus in the third year (each year beginning with Māgha) the month of Shrāvana is treated as adhika (extra i.e. malamāsa) and is followed by Shuddha Shrāvana; in the fifth year, after Pausha a last month, called Adhika Māgha is aded. Since there are 1860 tithis, vis-a-vis 1830 days, 30 tithis are omitted (titikshaya); each period of 61 days contains 62 tithis and hence 1 tithi is omitted after every 61 days so that effectively there is 1 tithi per day. Finally, since there are 1809 nakshatras in 1830 days, $87\frac{1}{7}$ days are taken equivalent to $86\frac{1}{7}$ nakshatras. The two are thus brought into concordance by counting 1 nakshatra per day and then after 87 days, the last nakshatra is to be repeated the next day as well. In each year, generally, the number of days in a month used to alternate between 29 and 30 starting with Māgha with the exception of the first year of a yuga when Māgha also used to have 30 days. In the 3rd and 5th years, of course, they had Adhika Shrāvana and Shrāvana after Ashādha of 20 and 30 days respectively. Similarly at the end of the fifth year, at the very end Adhika Māgha of 29 or 30 days.

I may emphasize here, althought Vedānga Jyotish was motivated by exact calculations of tithi and nakshatra, the error involved in their basic premises were quite significant. More accurate present day data yield:

$$\text{5 years} = 365.2422 \times 5 = 1826.2110 \text{ days}$$
$$\text{62 lunar months} = 29.53059 \times 62 = 1830.8965 \text{ days}$$
$$\text{67 nakshatra months} = 27.32166 \times 67 = 1830.5512 \text{ days.}$$

In Vedānga Jyotish all the three are treated as eqaual to 1830 days. Their year commenced on the winter solstice day and with the sun and moon in conjunction. Because of the above inequalities, the sun and moon will be slightly out of phase at the beginning of each consecutive yuga. The error piled up over a few yugas ought to have been perceptible to bare observations. So they must have had some method of correcting it by suppressing some intercalaries over a large number of yugas. Experts have made their own surmises but no direct evidence of what they did is now available.

Correct present day values for tithi and nakshatra day, together with their wrong values taken in Vedānga Jyotish (V.J.) are as follows:

$$\text{1 tithi} = 29.530588/30 = 0.984353 \text{ day; in V.J. } 1830/1860 = 0.983871 \text{ day}$$
$$\text{1 nakshatra day} = 27.32166/27 = 1.011913 \text{ day; in V.J. } 1830/1809 = 1.011608 \text{ day.}$$

The errors,although small, are not insignificant. Some data recorded in the Vedānga Jyotish period reveal precesion of the equinox. These data enable one to estimate the time of Vedānga Jyotish, Mahābhārata etc. by comparing with the present position of the same nakshatras. Such estimates place some of the early Vedānga Jyotish data around 1100-1300 BC.

Finally, in Vedānga Jyotish the ratio of the longest day to the shortest night at summer solstice is quoted as 3:2. the exact value depends very much on the latitude of the place. Assumming that the quoted value related to some place in Gāndhāra, present day calculations yield a figure 1.46 without making parallax corrections at surmise and sunset in determining the durations of daylight and darknes. It is a reasonable guess they were not aware of parallax effect. The same ratio, calculated for Babylon, comes to 1.49. Some western experts, on this ground, make a sunrise that the Vedānga jyotish astronomers might have just borrowed the number from Chaldeans without making their own measurements. But judging by the accuracy of their measurements of some of the basic data of the system, one may conclude that 1.46 is sifficiently close to 1.5, and they may have rounded off the results of their own measurements, with some errors in the determination of the sunrise and sunset timings, as 3/2.

(c) Siddhanta Jyotish period

The works belonging to this period are characterized by evidence that contacts had been established by about 100 AD between the Indian and Graeco-Chaldean astronomers. However, it is also very definite that there was no direct contact with the said group or the Greek schools at Alexandria, Rhodes or Greece proper. Historical facts point out that the Indo-Scythians (the Shakas and the Kushānas, in particular) coming to India and settling down here after the fall of the Maurya empire brought with them their knowledge of astronomy acquired by direct contact with Babylon and the remnants of the Seleucid influence left in their own original abode in and around Parthia. In India, for a long time, the Brāhmins who practised astronomy and astrology, used to be called Shākadvipi Brahmins, sugesting Shaka origin of these experts. As earlier mentioned, during the period 500 BC to the heydays of the Maurya empire, practice of astrology was not favoured in India and, as a result, original researches in astronomy had also dwindled. But at the beginning of the Siddhanta Jyotish period, the new knowledge coming from the west via the Shakas and Kushānas fired the creative interests of Indian savants, and many well-known astronomers flourished in the course of time - Aryabhatta (476-523 AD), Barāhamihira, Lātadeva, Brahmagupta, Bhāshkara, Munjala, Sripati, Sridhara etc. The most celebrated astronomical treatises of this age is Surya Siddhanta. In its present day form it contains 14 chapters, primarily related to genuine astronomical topics. It is a compilation of astronomical knowledge of the time and no authorship by a particular individual or individuals has been claimed in the traditions of those days. This text has served as a source book for astronomers to the present day. Almost equally well-known is a text called Pancha Siddhāntikā, compiled by Barāhamihira. It deals with summaries of five Siddhāntic systems: Paitāmaha, Bāshishtha, Romaka, Paulisha and Surya - arranged in order of increasing accuracy. All these are presented as 'aparusheya' i.e. knowledge revealed by gods or mythical persons. The first two systems are ascribed to the god Brahmā and an ancient sage Bashishtha respectively. Romaka and Paulisha, as their names suggest, are taken to be of foreign origin. However, according to alternative opinions, Romaka contains knowledge received by the sage Romasha from the god Vishnu him-

self and Paulisha is asribed to the sage Pulastya. On the origin of Paulisha' controversy remains because there was an astronomer named Paulus in Alexandria; however, he wrote only an astrological treatise. Surya Siddhānta was presented as revelations by the Sun god to an asura named Maya who, acording to mythology, was the architect engineer of the city of gods. A detailed perusal of this treatise pesuades the persent day reader that it has no overlap with, nor is it influenced by, Ptolemy's Syntaxis. It uses the longitude of Ujjaini as the reference point of measurements. Some of the positions of stars listed in it, lead to an estimate of its age around 280 AD.

Suryasiddhānta is based on a geocentric picture - it states clearly that the earth is suspended in space at the centre of the celestial sphere and its self-supporting force is provided by almighty Brahmā. It defines, in a precise scientific way, the earth's polar axis and defines two pole stars, one in the north and the other in the south; of course, one in the south does not really exist and must have been imagined by analogy with the Dhruvatāra. The equator is then defined correctly as in modern astronomy. Several cardinal points are then defined on the equator, one of them called Lankā at the intersection of the equator with the meridional line through Ujjaini. This Lankā is, of course, a fanciful name and has nothing to do with the island of Sri Lankā. Suryasiddhānta takes it for granted that the facts about ecliptic, the sun's path, is already known to the reader. It then defines the 12 signs of the zodiac - Mesh, Vrisha etc. It is clear from the text that the first point of Aries (Mesh) was coincident witht the vernal equinox at the time of its compilation. It clearly explains the occurrence of seasons related to the sun's positions on the ecliptic. Each sign of the zodiac was defined as a 30^0 segment of the ecliptic and the starting point of the zodiac was specified to be at one of the intersections of the equator and ecliptic. That is to say, the signs are not coincident with asterism, i.e. the individual star or constellation assigned to it; their boundaries are precisely defined in terms of angles. Although Suryasiddhanta was not aware of the precession of equinox but it did not identify the equinoxial point with any fixed star. The actual points of intersection of the equator and ecliptic used to be determined by direct experimental observations starting about 280 AD. The length of the year accepted in it was taken from Aryabhatta and was larger than the then prevalent value propounded by Ptolemy. Thus Siddhānta literatures appear to have very little influence from Syntaxis.

The Siddhanta astronomers prescribed the beginning of a solar year as folows: for astronomical purposes it starts at the moment the sun crosses the vernal equinox and for civil purposes it starts on the following day. Suryasiddhānta lays down Vaishakha as the name of the first solar month. Each solar month is defined as the time taken by the sun to cross a 30^0 arc on the ecliptic. The difficulties associated with thes definition, namely, fractional days in a month and unequal lengths of different months, have already been discussed. The precise moment when the sun crosses from one sign of the zodiac to the next is called a Sankrānti; since it comes at any time during the day or night, conventions had to be adopted to reckon the first day of the month for civil purposes.

Suryasiddhānta recognises lunar months as well. During the Vedānga period average lengths of lunar and solar months, taken as basic data for computations, contained significant errors. In the beginning of the Siddhānta period, the intercalaries were suitably adjusted on the basis of more accurate data and the earlier errors were also corrected. Experts believe, what the Siddhanāntists adopted was not identical with the Chaldean 19 year cycle with 7 intercalaries. Ultimately, however, very different rules were laid down for identifying intercalaries (malamāsa) from actual data on the beginning and end of the lunar and solar months.

From one new moon to the next is taken as the definition of an amānta or mukhya chāndramāsa. the lunar month so defined is given the same name as that of the solar month in which the initial new moon occurs. The solar month is, of course, reckoned from one sankrānti to the next, as mentioned earlier. If a lunar month falls entirely within a solar month then the former is counted as an adhika prefixed to the name of the particular solar month and is a malamāsa. The next lunar month which then starts towards the end of the same solar month also carries the name of the latter but prefixed with shuddha. The lengths of solar and lunar months are, of course, irregular and the largest lunar months are sometimes slightly longer than the shortest solar months - Agrahāyana to Māgha. On the other hand, the minimum duration of a lunar month is always shorter than all the solar months except Pausha. Thus a malamāsa, as defined above, can occur in all months except Pausha. On rarer occasions, a large lunar month can stretch completely over one of the months from Agrahāyana to Māgha. No new moon then occurs in that particular solar month and the corresponding lunar month is called a kshaya (decayed) māsa. Siddhānta Jyotish also prescribes a system of purnimānta or gauna (inferior) chāndra māsa reckoned from one full moon to the next. It starts a fortnight earlier than an amānta lunar month and is given the same name.

Without going into any further details of Siddhanta Jyotish, I shall at the end emphasize that great advances were made during this period in goemetry, trigonometry and algebra as a spin-off from the activities in astronomy. The most interesting example is the definition of the sine and (1 - cosine) functions of an angle by Aryabhatta in the context of the double chord shown in Fig. 6. The Greek school tabulated the double chord itself for different values of the radius R and angle θ. Aryabhatta realised that the ratio of the double chord and the diameter depends only on the angle and defined that to be the sine function. Thus only the tables of the sine were prepared avoiding unnecessarily repittious tables for different values of R.

4.7 The Arabs

They were late starters in astronomy and entered the field around 1000 AD. Initially they learnt everything that was already known in Indian and Graeco-Chaldean astronomy. They were prolific translators and rendered all such available foreign texts into Arabic. Ptolemy's Syntaxis was named Almagest in their translated version. As a result of their intimate contact with the Indians, one finds a close resemblance between

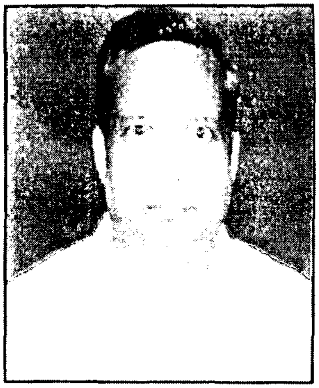
the Indian nakshatras and the Arab manāzils (houses), just as the Chinese Hsius also have many similarities. Originality of the Arabs flourished in the developments of algebra (derived from an arabic word), geometry, plane and spherical trignometry for very useful and straightforward applications to astronomical calculations. The tangent and cotangent functions were introduced by them, presumably for problems related to the gnomon (Fig. 1) where the lengths of the shadow and the gnomon are related through the tangent of an angle defining the sun's position.

The Arabs also played a great role in observational astronomy by setting up laboratories and innovating many instruments. The observatory at Samarkhand under the leadership of Ulugh Beg was famous. Very intricately and beautifully built astrolabes came to india from the Arabs during later days of our Muslim rule. Al Battani, Nasiruddin Tusi, Ulugh Beg are some of the outstanding names of Arab astronomers.

In spite of the great advances made by them in astronomy, the Arabs always used a lunar calendar and never introduced the system of luni-solar adjustment. As a result it is well-known that all Muslim religious occasions, fixed according to lunar calendar, shift gradually to different seasons. Of course, they don't have to be related to fixed seasons.

5 Conclusion

I conclude this long-drawn historical account with the hope that, although not of much value to specialists in history and astronomy, it will help a general reader in creating a wider mental horizon transcending the narrow bounds of his immediate preoccupation. The realisation of the antiquity of human civilisation, of the pains and hazards some pioneers undertook in quest of knowing the wide world and gaining from the intellectual fruits of far-away nations, can only help one shedding some amount of unwarranted intellectual arrogance. It helps also to be discerning and take lessons from the rise and inevitable fall of once impregnable empires confident of the powers of their militia and armaments. One may thus learn to sharpen one's value judgements by placing one's faith in the more tangible legacies of human civilisations in the field of science, humanities, arts and crafts that continually elevate and ennoble, and have kept active, without our knowing, an inexorable process of evolution, not of the Darwinian kind, but superior to it.



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Astronomy of Vedic Times

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1 Introduction

The topic includes meaning of Veda, astronomy their inter relation, time and accuracy.

In element form Veda is the whole creation, this is same as *Brahma, Virāta, Purusa* etc. Other form of Veda is literal which is seen as books known as Vedas. As four legs of *Brahma*, Veda has four parts which has been described as 4 *Purusas* with a total of 16 *Kalās* or 4 *vyūha* (structures) of *Pāñcharātra* described in *Bhāgawata.* Its every verse is expressed by some *rsi* in word form and is thus human, but the central point and the method to realise are super-human. This is final truth as the unity among seemingly different descriptions of same element.

Corresponding to 3 meanings of verb *'vid'* and 3 steps to perception Veda means triad of *Rk, yajur* and *sāma.* Before that, the foundation was *Atharva* which is knowledge of formless *Brahma, Mundakopanisad* (school text) describes in first 5 verses appearance of *Atharva* and then its classification into 4 Vedas and 6 *angas.* In word form *Atharva Veda* contains politics, medicine, crafts and other practical sciences. After practical knowledge only, its essence or philosophy becomes clear. Thus, after *Atharvaveda,* its principles appeared as 3 Vedas. Tray or triad of Vedas, means 4 Vedas. This word *Veda* always means four in astronomy or literature.

Trayī or *Veda* = Root *Atharva* + 3 principles (*Rk, yaju, sāma*)

= Source Brahma + 3 parts due to 3 gu'as

= Original uniform world + Form, motion and field of influence (Taittīrya Brahma'a 3/12/9/1)

= Eternal Brahma + Forms of *Agni, Vāyu, Ravi* as *Rk, yaju, sāma* (Manusmrti 1/23)

We know an object A due to 3 reasons–

1. A exists. Vid means to exist, in that meaning *Rk* Veda describes form of objects (shape, weight etc).

2. Some information about A reaches us through light, sound etc. This is getting essence of A, that meaning of '*vid*'is to gain. Veda related to motion is *yajur.*

3. A can be known only if its *sāma* (influence field) extends upto us in form of gravitation, light etc. Different fields of sun, moon, earth are named as *Brhat sāma, rathantara sāma* etc, which are classified according to *'stoma'* numbers 9, 15, 21 etc. *Sāma* is the basic cause of knowledge, so *Krsna* has called himself *sāma* among Vedas (Gt$\not c$ 10/22). This is third meaning of verb *vid* = to know.

Above 3 steps – existence, motion and perception – all are against background. Existence of object means that it is different from its surroundings. Motion is seen

against a fixed reference. Finally, perception is due to previous store of knowledge and comparison. Covering of all is *Atharva Veda* which is *Brahma.*

2 Astronomy and Veda

Jyotisa means study of bodies with light (*jyoti*).Among these, sun and stars have own light and planets have reflected light. This is limited meaning related to mathematical part only. In that part also, reference of stars at infinite distance is *Atharva Veda,* position, size and distance of sun, planets is *Rk* Veda, their motion is *yajurveda* and their effect (season, eclipse etc) is *sāma* Veda.

Creation is form light *Jyotisa* is science of creation starting from formless to 7 lokas and 14 classes of beings. Modern astronomy is limited to study of cosmic bodies only. Study of earth is geology, study of living beings is biology (two parts of Botany, Zoology) and study of man comes under medical science. In *jyotisa* cosmology is called *samhitā.* Being part of the same great scheme, incidents of human world depend on heavenly bodies, this study is *phalita jyotisa.*

Stages of creation, its size and shape, dynamics, all can be known in detail only through *jyotisa, Vrddha Vaśistha Siddhānta* (1/5 - 7) has called *jyotisa* as eyes of Vedas in human form. This has been explained in Siddhanta Siromani of *Bhāskarāchārya* (1/9-12)- Veda depends on *yajña* whose time is known from *jyotisa* only, thus *jyotisa* is foundation of Veda. This is limited meaning related to calculation of calendar *Rk* and *yajusa* readings of *Vedānga jyotisa* describe this aspect only. Concept of time is part of motion explained in *jyotisa* (motion = distance ÷ time). Two meanings of time are explained in *Surya siddhanta* (1/10) - One *Kāla* (time) is death which destroys the world. This is *Kśara purusa* (decaying world) of *Bhagavata Gita.* The other is *janya kala* which is the time measured by periodic motions, e.g. second from pendulum, day from axial rotation of earth, month from moon's motion (*māsa* = measured time, month). Modern and ancient astronomy related to observation and calculation describe *Kśara Brahma* only, but it is necessary to know *parātpara avyaya* and *akśara* brahma also to understand the scheme of creation. As per *Purusa sūkta* verse 3, these 3 parts are unseen and permanent in heavens.

Cosmology of *Purusa sūkta* has been explained in Sūrya Siddhanta chapter 12 in 12 verses (12-23)- Āditya i.e. influence field of sun (*sāma*) are of 12 types described in Vedas. Thus Surya Siddhanta gives the fullest description of vedic *jyotisa* among the currently available texts. In addition to the elements and words of *Purusa sūkta,* this also explains 25 elements of *sānkhya* and 4 *vyūha* of *Bhāgavata (Vāsudeva, Sankarsana, Pradyumna and Aniruddha).* This is *ādhidaivika* meaning of *Bhāgavata* concept in line with Vedas. The physical meaning of *Bhagavata* got distorted due to historic incidents which have been objected to by *Swāmī Dayānanda* in *Bhāgavata Khandanam.* But it is clear from *Sūrya siddhānta* that its astronomical meaning is same as that of *Purusa sūkta.*

Unity of *Veda - Bhāgavata* - astronomy - Four parts of *Brahma* described in *Māndūkya Upanisad* are explained in context of *Purusa sūkta* and *vyūha* of *Bhāgavata.*

1. *Śiva advaita pāda (parātpara)* - This is formless, beyond perception and thinking etc. According to *Bhāgavata* this is *Vāsudeva* (*Vāsa* = space, *deva* = light)

2. *Prājña (Avyaya)* - This is with *vijñāna* and *Avyaya* means that sum total of its 5 *kalās* is constant. According to *Bhāgavata*, this is *Sankarsana* (attraction) which is cause of formation and mutual arrangement of heavenly bodies.

3. *Taijas (Akśara)* - This has internal consciousness. According to *Gītā* , this is 'akśara' which is key identification of decaying objects which remains fixed. *Bhāgavata* calls it *Pradyumna* (=lighted). Each object spreads its influence, light etc as per its nature.

4. *Vaiśvānara (Kśara)* - This is visible world whose each form is decaying slowly. This is called *Aniruddha* (unlimited forms) in *Bhāgavata.* Infinite varieties have been classified in 14 *bhuvana* or *sarga* of *sānkhya.* This form is worshipped as *'ananta'* (infinite) on 14th dark night of *Āsvina.* This is mentioned in 3rd verse of *Purusa sūkta* and continues for 14 verses upto 16th.

3 Veda and Jaina Astronomy

Jaina philosophy is unrelated and considered anti to Vedas. If it is called parallel to Vedas, Jain and vedic followers both will be angry. *Brahmagupta* and *Bhāskarāchārya* have taken jaina astronomy as part of Bauddha philosophy and criticised it. Incompleteness of Bauddha thinking was that they ignored astronomy and medicine, thinking it part of vedic thought. Surgery was taken anti to principle of non-violence and it was uprooted. But Jaina philosophy does not oppose astronomy. It has texts like Surya Siddhānta as Surya and *chandra prajnapti* which explain vedic astronomy. This is separate from Vedas only in the sense that it has separate methods. But this is helpful in understanding vedic astronomy. It is evident from the fact that *Kumārila Bhatta* had to study under Jaina prophet *Mahāvira* (same as the mathematician *Mahāvira*) to re-establish vedic thoughts. *Śankarāchārya* carried forward his work. Parallel development of Jaina and vedic streams of astronomy is indicated by the following–

1. There are 24 *Tirthankaras* of Jaina like 24 avatāras of Vishnu (24 forms of Prakrti = nature in sākhya). Earlier *Tirthankaras Rsabhadeva* and *Bharata* are mentioned in Vedas also. They were rulers of India which is home of Vedas. How their tradition could be anti to Vedas ?

2. Veda is complete and eternal truth, but it cannot be used as a text book. Practical subjects like agriculture, crafts, mathematics, biology, chemistry etc will be in different form and of various types. Form of text books differs as per current language, state of society, standard of education, class etc. Thus the education system in force by Govt. or society will be worldly or Jaina education. Therefore, all Jaina Tirthankaras have been kśatriya kings. Western scholars going by the name Brahma'a texts have concluded that these were in support of Brahma'a caste which was opposed by kśatriyas in form of Jaina or Bauddha religion. Same scholars tell that *Aitareya Mahidāsa* (another of *Aitareya* Brāhmana) was dāsa (slave). Even Tāndya

Mahabrāhmana is by Tandi, which means *sudra* in Western Orissa, *Mahābrāhmana* also means the same.

3. Jains astronomy describes planetary orbits as plane projection on earth. For a plane map, a sphere is presented by 2 circles, all planets and stars are shown in both. Thus, we have in Jaina *jyotisa* 2 suns, 2 moons and 54 asterisms. Same method is used in school atlas, navigation and cadastral survey are based on such maps. As jaina *jyotisa* was not current later on, *Brahmagupta* and *Bhāskarāchārya* have criticised it, unaware about its different scheme. Sun goes northwards upto $23\frac{1}{2}^o$ (Tropic of cancer). Moon goes 5^o more northwards (or up in map) upto Delhi which was capital of kings of moon-clan. Planetary orbits have been described in *Visnu Purāna* (2/8) and other *purānas* according to this concept only. From the now extinct part of this *Visnu Purāna, Brahmagupta* wrote *Brahma sphuta siddhānta* in 628 A.D.

4. *Meru* has been described in various purānas exactly as per Jaina astronomy. Kutub Minar (*Vishnu dhvaja*) of Delhi is model of same *meru* (Jaina astronomy by S.S. Lishk or Siddhānta Darpa'a part 2 by A.K. Upadhyay). Same *meru* has been described in Vedas also.

5. Mathematical year, month and day are always the same, but various methods are in use for practical convenience. Year is of $365\frac{1}{4}$ days, but in practice, it is a round number of 365 or 366 days. A tithi (lunar day) may start mathematically at any time, but practical start is from local sunrise. Therefore, 3 streams of astronomy were always in use for 3 purposes – (1) Siddhanta texts were for position of *nirayana* planets and long term calender. (2) *Vedānga jyotisa* for ayana year (tropical = rtu year - Rk jyotisa verses 6, 7, 8, 9, 22, yājusa jyotisa 6, 7, 8, 9, 28, 30) This is used for yajña like *Fasali* years of middle ages. (3) Jaina jyotisa is method to prepare maps from same principles. This is used for mapping of earth, geography books, navigation charts etc.

Western scholars realise these facts for Egypt and Sumeria, but they assume 3 separate eras in India for 3 types of calenders. Carl Sagan has quoted on page 106 of his book Broca's Brain-

A leading historian of ancient science and mathematics Otto Nengebauer (1957) remarks that, both in Mesopotamia and Egypt, two separate and mutually exclusive calenders were maintained - a civil calender whose hall mark was computational convenience, and a frequently updated agricultural calender - messier to deal with, but much closer to the seasonal and astronomical realities, many ancient cultures solved the two calender problem simply by adding a few day holiday on the end of the year...".

4 *Śaka*

and *Samvatsara* - In Vedas, year has been indicated by *vatsara* and its 5 derivatives with 5 prefixes. Among these words *samvatsara* is most famous. *Satapatha Brāhmana* (11/1/6/12) has indicated its origin from *sarvatsara.* Prajāpati in form of time is sarvatsara which is ecliptic circle (Satapatha Brāhma'a 1/4/1/34) Earth is always

moving, or its path is curved at each point – both ways it is *sarvatsara*. This has become *samvatsara*.

Samvatsara has been used in astronomy in two senses. Now all calendars are called *samvatsara* or *samvat* in short. *Vatsara* or *vatsa* is off spring (*vatsa* = oust, from mother's womb). This is produced by annual motion of earth or *Prajāpati*. Names of years have been classified as per starting tithi of solar year.

Name of lunar year	Start of solar year	Lunar stars
1. *Samvatsara*	*Māgha śukla* 1st to 6th	*Śravisthā* (0) to *Aśvinī*
2. *Anuvatsara*	*Māgha śukla* 7th - 12th	*Aśvinī* (5.4) to *Ārdrā* (10.8)
3. *Parivatsara*	*Māgha śukla* 13th *Māgha Kr* 3	(10.8) to *uttarāphālguni* (16.2)
4. *Idvatsara*	*Māgha Krsna* 4 - 9	(16.2) to Anurādhā (21.6)
5. *Idāvatsara*	*Māgha Krsna* 10 - 15	21.6 to *Sravisthā*

Lunar year started from *Māgha śukla* 1st and stars were counted from *Śravisthā (Dhanisthā)*.

Taittirya Brāhma'a (30/10/4) has named *anuvatsara* as *iduvatsara* also. This also mentions a sixth type of year *'vatsara'* which is used in *yajur jyotisa*. As present 360 days year is called *vatsara* (civil year). This is suitable for preparing annual routines of Govt. offices or educational institutes, all its 12 months are of 30 days each. In an year of 365 days, last 5 days will be year-end holiday like Xmas holidays or haz at end of Islamic year. In each 4th year there will be extra 6 days called *sadāha*. In *yajusa jyotisa* first 5 years are of 366 days each = civil year of 360 days (*vatsara*) + *sadāha* of 6 days. Sixth year is only *vatsara* without addition of *sadāha*. Years are classified according to the lunar tithi at beginning of solar year. Due to an extra day in each year, in 25 years of 5 yugas, 6 years are lapsed as 5 types of years do not come in each yuga. According to *Rk jyotisa* calculations, *yuga* is of 19 years in which there are 5 *samvatsaras* and 14 years of other 4 types. Its details are in *Vedānga jyotisa* by *Prabhākara Holay*.

Under present system, there is only one type of year. This is called *samvatsara* because, lunar year is almost similar to solar year due to intercalary months (*samvatsara*=moves with almost equal speed).

Śaka means *sakti* or strength. First number is week indicated by a thin 'kuśa' (straw) with which a pointer (*śalākā*) also is made. In every language, kuśa shape means one.*Śalākā purusa* also means the top man. Kuśa gains strength by two methods to become *śaka*. Big trees in shape of kuśa (pillar like) is called śaka. In north India, sal tree is called *śaka (sakhua)*, *Buddha* was called *śākyamuni* as he was born in sal forest region of Nepal plains. He was not of śaka tribe but was descendant of Rāma

of solar dynasty. According to geography of Purā'as by Muzaffar Ali *Śaka dvīpa* was south east Asia and north west of India in Central Asia and south east Europe. This abounded in *śaka* trees (pillar shaped). South east Asia was among 9 parts of India itself, thus adjacent parts of central Asia and Europe were *śaka dvīpa*. Second type of *śaka* is formed by tying many *kuśa* together in a bundle. This is intuitive process of counting in which we mentally prepare bundles of 5 *kuśa* each -

IIII, IIII, II ....

with this meaning, *śaka* is the cumulative count of years from a point of time. This concept is universal, hence Mexico history states that straw bundles were used to count thousands of years in Mayan calender. This mistake has occurred due to wrong translation of mathematical meaning of *śaka*.

For astronomical calculations, we calculate by count from the reference origin. For that, we calculate *śaka* first. In last 1900 years, Indian astronomy has used *śālivāhana* years for calculation, so this calender is called *śaka*. *Vikrama* year is used for deciding festivals, so this is called *samvat*. Both are *śaka* as well as *samvat*. Similarly, there are *kali, samvat, kalchuri samvat, saptarsi samvat* and *Yudhisthira śaka, Śū*draka śaka etc.

Only solar year or only lunar year also is *samvat* because all years are equal, whose short form is *'san'*.

5 Meaning of Yuga

Two words are derived from *yuga-yoga* (addition) and *yugma* (pair). According to both derived meanings, *yuga* is a period in which two or more cyclic rotations are completed. For example, in four years yuga with a leap year, cycles of daily motion of earth (1461) and annual motions (4) both are complete. In 5 years *yājusa yuga* sun and moon make almost complete revolutions. These are more matching in 19 year yuga of *rk jyotisa*. According to *Sūrya siddhānta*, all planets make complete revolutions in *yuga* of 43,20,000 years. Cycles of apogee and nodes of planets are completed in 1,000 yugas which is a day of Brahmā called *Kalpa*. Galaxy is located inside *tapa loka* which corresponds to sixth *ājñā chakra* of man controlling the mind. Thus, axial rotation period of galaxy is cycle of cosmic mind (=*mana*) called *manvantara* of about 30 crore years.

Vāyu purūna (57/17) tells *saptarsi vatsara* of 3,030 *mānusa* years. Same purā'a (99/419-422) tells it of 2700 *divya varsas. Rsis* were seers of Veda and *divya* means lighted or sun, thus divya year means solar year (tropical) according to *rk jyotisa*. Moon controls *'mana'* (hence called moon), *rkśa* means *rsi* and stars both. Hence *mānusa* year of *saptarsi* means moon sidereal year. Moon makes one sidereal rotation of earth in 27·2 days, 12 such rotations are sidereal year of moon.

$$3,030 \times 27.2 \times 12 = 2700 \times 365\frac{1}{4} \text{ solar year}$$

Thre is no real motion of *saptarsi* in sky, this is merely a result of *vedānga jyotisa* calculation.

100 years = 19 years *yuga* of *rk* or *yājusa* × 5 + 5 years *yājusa yuga*

If we calculate according to *vedānga jyotisa* moon will be in next star after lapse of 100 years. Hence, it is said that *saptarsis* cross one star in 100 years or a cycle of 27 stars in 2700 years *yuga*. (For details see siddhānta darpana part 2 chapter 6)

Four legs or quarters of a *yuga* are named after 4 years *yuga* of *Gopatha* or *Aitareya* Brāhma'a

Kali = *Kalana* (calculation) starts = First year

Dvāpara - *Dvā* = two, 2nd year

Tretā - *Tri* = three, 3rd year

Krta = complete, *yuga* completed in 4th year.

Each year is of $365\frac{1}{4}$ days. If we count 365 days, after one year$\frac{1}{4}$ days (1 leg) extra remains, two legs after 2nd year, 3 after Tretā and full day after *Krta (satya) yuga*. *Gopatha yuga* should start in *godhūli* (evening twilight, like hebrew day) at 6 pm. then *kali* will be completed next year same day at 12 pm. when everybody will be sleeping. Dvāpara will be completed at 6 am. when people start rising. Tretā will end at 12 am., when people are standing. Krta year will end again at 6 pm. (one day extra) when people will be moving to return home. Hence it is better to keep moving as advised.

In Sūrya siddhānta, order of *yugas* is reverse. Here also *kali, Dvāpara, Tretā* , *Krta* have 1, 2, 3, 4 parts each, but each part is of 4,32,000 years.

In astrology, future of man is considered dependant on planetary motions. It indicates future of nations also. Thus, historical eras should also depend on planetary motion Geology indicates great upheavals due to glacial cycles and ancient legends of every country start with great floods. Historical cycle should be linked with glacial cycle but cobweb of imaginary linguistics has been created to find history. In 1925, Milankovitch explained glacial cycle on basis of planetary motion. Glacial cycle is due to mutual rotation of vernal equinox and apogee.

Apogee cycle = 1,00,000 years

Cycle of vernal equinox in opposite direction = 26,000 years

Their mutual rotation will be in 21,000 years. Taking slightly lower value of apogee cycle, every planet will have some residual motion and relative motion of equinox point will be 21,600 years cycle. This value has been taken in Sūrya siddhānta.

Point of summer solstice was with perigee 11.2, 33.2 and 60.1 thousand years ago. In 1250 A.D., it was with point of summer solstice, now they are separated by less than 10^o. Winter portion in north hemisphere is smaller as earth moves fast. Thus in long summer, most glaciers in north hemisphere get less heat and glaciation starts (see pages 284-291 of Our Planet, the Earth)

Last glacial age was over about 10,500 years ago. Accurate times can be found from current calenders, equinox movement, or horoscopes. By this method, important dates are -

1. Rule of *Vaivasvata Manu* - 8,576 BC
2. *Paraśurāma* era (*Kollam* year of Kerala) – 5,177 B.C. (Then 9 generations before Rāma in solar dynasty, Mūlaka was saved by hiding among women)

3. Rāma - 4,433 B.C. 11th February 10-48 LMT of Ayodhyā
4. 3228 B.C. 19th July midnight – Birth of *Śrikrsna* at *Mathura.*
5. 3138 B.C., Mahābhārata war, start of *Yudhishitira saka* when *saptarsi* were in *Maghā* star.
6. 3102 B.C. 17/18 February, Ujjain midnight, start of Kali Samvat.
7. *Gautam Buddha* - Birth 31-3-1886, Vaiśākha pūrnima, friday. Demice 28-3-1807 A.D., Vaiśākha pūrnimā, tuesday, sunrise.
   Magadha dynasties -
   3138 - 2132 B.C. – Bārhadratha dynasty
   (3078 - 2848 B.C. – Institute of Śaunaka compiles Purā'as etc.)
   2132 - 1994 B.C. – *Pradyota* dynasty
   1994 - 1634 B.C. – Śiśunāga dynasty
   1634 - 1534 B.C. – 9 kings of *Nanda*
   1534 - 1218 B.C. – *Maurya* rule
   1218 - 918 B.C. – Śunga rule
   918 - 833 B.C. – Ka'va rule
8. *Śankarāchārya* - 4-4-509 B.C., 2152 IST, Vaiśākha śukla 5th, birth
   833 - 327 B.C. - Āndhra dynasty
   611 B.C. – Śaka mentioned by Varāhamihira starts. He was in time of Vikramāditya but his date of birth is thought in śaka starting 135 years after *Vikrama* śaka.
   327 - 82 B.C. – *Gupta* dynasty
   457 B.C. – Śūdraka śaka
   57 B.C. – *Vikrama* samvat
   78 A.D. – Śālivāhana śaka
9. About 750 A.D. – Gorakhanātha.

This chart indicates that the historic *yuga* of 5000 years is half of glacier free era of 10,000 years. After gradual rise of 5000 years, there is decline in next 5,000 years. Incarnations of god have been approximately at intervals of 1250 years which is one fourth of historic yuga. Difference in times of *Paraśurāma, Rāma, Krsna, Buddha, Sankara* and *Gorakhanātha* is almost same. About 1250 years after Gorakhanātha, now it may be the time of resurgence of India.

6 Angiquity of jyotisa

Veda indicates its own time through its limb of jyotisa. Mundaka upanisad tells that Brahmā taught Veda to is eldest son *Atharva.* This is time of human Brahmā. *Abhijit* star ruled by Brahmā was pole star then, about 15,000 years ago. This time may be earlier by 26,000 years or its multiples. At present, [1]ravana starts After *abhijit* star, vedānga jyotiā starts star counting with Śravana. Written form of Vedas became extinct by demons and during great floods. Thus the current version of vedānga jyotisa should be from time of *Vaivasvata Manu.* Jaina Tirthakaras started before that, hence jaina astronomy also should start then.

Sūrya siddhānta was written by *Maya asura* as taught by Sūrya. This Sūrya is Visvasvān, father of *Vaivasvat Manu,* his time also will be about 10,000 years ago. Sometime after *Manu, Maya* and then Rāma appeared. *Maya's* daughter Mandodar was married to Rāva'a who was elder to Rāma. Thus, Sūrya siddhānta methods were definitely stabilised by 5,000 B.C. It is evident from horoscope of Rāma and other astronomical references, that Sūrya siddhānta was followed in his time. Ruler of Lankā before Rāva'a was called *Kubera.* Lankā has been taken as 0° longitude in Sūrya siddhānta, thus Lankā time will be called world time in modern parlance. Meaning of *kubera* is same – *Ku* = earth, *Bera or Bela* = time.

In addition to these literary evidences, there are 3 astronomical references about time of Sūrya siddhānta.

1. Value of solar year – First chapter verses 29-34 gives revolution numbers of planets in a yuga-Revolution of nakśatras (stars) substracted by solar revolution is solar day. Solar days divided by solar years (sun revolutions) gives 365. 2587565 days in sidereal year. Here there is accuracy of 1 day in 1 yuga i.e. 1/50 seconds in value of solar year. Astronomical epheremeris 1998, page 2 gives sidereal solar year = 365·256363. Thus, year of Sūrya siddhānta is greater than modern year by 0·0023935 days = 3 minute 26·7984 seconds.

   Axial rotation of earth is being slowed down due to tidal friction mainly by moon's attraction. In ancient times, axial rotation was faster i.e. day was shorter. Each year, solar day is increasing by 2×10^5 seconds. If solar year is considered fixed, then day was smaller in Sūrya siddhānta time by $206 \div 365.25 = 0.566$ second. This time should be $0.566 \div 2 \times 10^{-5} = 28{,}300$ years ago.

   To explain glacial age, equinox motion has been counted from apogee. In that system, solar year also should be counted from apogee to apogee. This year is slightly bigger of 365.259635 days. There is lesser difference of Sūrya siddhānta year from this value. This calculation gives Sūrya siddhānta epoch about 10,000 year ago.

2. Eccentricity of earth as *mandaphala* is declining at the rate of 3 minute every thousand years. Sūrya siddhānta (2/34) gives it as 14^o *mandaparidhi.* Then *mandaphala* = $14^o \div 2\pi = 2^o13'41''$. Now, it is about $1^o55'$. Difference of 18' will be in about 6000 years. (Sūrya siddhānta by Mahāvra Prasad, page 132). Eccentricity was 0.020 about 20,000 years ago compared to present value of 0.0167. Value of Sūrya siddhānta (0.018) will be about 10,000 years ago.

3. Inclination of earth's axis– Sūrya siddhānta (2/28) gives max declination as 1397. On dividing by 3438, this will give sine of that angle, thus inclination of earth's axis is 24^o. At present this is declining and the current value is $23^o26'$. Small fluctuations of this value is in cycle of 41,000 years. Bigger cycle is of 2 lakh years between values of 22^o and 24.5^o. Now it is declining from max of 24^o to 22.7^o. In 3000-8000 B.C. It was $24^o \pm 0.01$. This also gives epoch of Sūrya siddhānta in 8000 B.C.

7 Accuracy of Sūrya siddhānta

1. Value of Sūrya siddhānta *yojana* has been found by comparing earth diameter given in *yojana* with modern value in kilometers (Sūrya siddhānta 2/59). Thus 1 *yojana* = about 8 km. *Yojana* has been defined in two ways. One is based on earth size which is like definition of nautical mile or old standard of metre. The other definition is linked with speed of light which is like latest concept in modern physics (siddhānta darpa'a, part 2 chapter 1)
2. Surya siddhānta chapter 12 gives planetary distances. Among them, distance of moon is correct according to value of *yojana* on earth. Distance of sun and star planets will be correct if stellar *yojana* is assumed equal to 27 earth *yojanas.* In Sūrya siddhānta, bhū = earth and 1, *bha* = star and 27. Thus, it is proper to take stellar *yojana* = *'bha'* yojana = 27 *yojana.* This is not a clever trick only, distance of all star planets comes correct by this. This also shows that relation between orbital period and distance of planets as per Keplar theory was known accurately.
3. Main part of apogee movement of sun is included in precessional motion. This gives correct value of day 10,000 years ago. Residual value of *mandoccha* is much lesser than the modern values. One benefit of this scheme is that it correctly explains historical era. Others benefit is that for calculations of upto 10,000 years, motion of apogee need not be taken into account.
4. Calculation of true planets is done only in four steps compared to 150 steps in modern astronomy, still it is more accurate (Siddh⁄ꞓnta darpa'a,part-2, chapter 5)
5. Size of galaxy- This has been determined in modern astronomy in 5 steps after 1930-

   (a) By parallax of moon from two places on earth, we get ratio of earth diameter and moon distance.

   (b) Ratio of distances of moon and other planets.

   (c) From opposite points of earth orbit (at six month interval), parallax of nearer stars is calculated. This is of order of thousandth of a second and accuracy is difficult.

   (d) From distance of about 100 nearer starts we estimate motion of sun, relation between light and distance of stars.

   (e) From star colour, its total light and distance is estimated. Each step causes many errors, and estimate of 1 lakh light year diameter of galaxy is very rough. Star lights are absorbed by intervening dust also.

   In Indian astronomy, there are three single step methods giving same diameter of 1 lakh light year when we take stellar *yojana* = 27 earth *yojanas*–

   (a) Three regions of spread of sunrays have been described by Bhāskarāchārya like 3 stoma of Vedas. Heat is upto earth orbit, strong light upto saturn and at end of galaxy it is dim like a star. The distance at which sun looks like a star should be diameter of galaxy.

   (b) Sūrya siddhānta (12/81, 82) tells that all planets will move the distance equal to circumference of galaxy in a day of Brahmā (432 crore years). Similarly, man covers circumference of earth in his life while moving within his house only.

(c) Distance increases according to revolution period, size of Brahm$\not{E}$'^{2}a (galaxy) will be related to *Kalpa* / day of Brahmā.

6. Concept of ***Loka*** Starting from man, sizes of earth, solar system and galaxy are successively larger by 1 crore times. There are crores of Brahmā'^{2}a,hence there is a bigger sphere of svayambhā. This is basis of meanings of Ko°i (= ends, or 10^7) and *kharva* (= particles, 10^{11}).
   Average of man's height width = 1·2 meter
   Diameter of earth = $1{\cdot}2 \times 10^7$ m
   Solar system = 10^{14} meter
   Galaxy (Brahmānda, paramesthi) = 10^{21} m= 10^5 light year
   Svayambhū sphere = 10^{28} meter
   Real visible universe is only 0.4×10^{27} m as estimated. Thus *purusa sū*kta verse 1 tells that purusa extends 10 times more than bhūmi (visible universe). From 2 spheres of earth-solar system, we get 3 lokas *bhū, bhuvah, svah.* Thus we get 4 lokas between sun-galaxy-universe- *mahar, janah, tapa, satya.* Each world is a *kharva* (particle) for next larger world and its number is 10^{11}, hence *kharva* = 10^{11}.
   10^{11} = number of neurons in human brain
   = number of stars in galaxy
   = number of galaxies in universe.
   Limit of each world is 10^7 times its size. Thus Koti=limit and 10^7.
7. Distances of stars - Veda has used unit of 5 earth *yojanas* for stellar distances (M.B. Panta in Vedavat *Pune,* 1987).
   Beta crucis star of southern cross has been called triśanku. Its distance is 207 light years. Meaning of triśanku is same, it is 3×10^{13} mahāyojana = 207 light year. Similarly, Argo Navis at 652 light years has been called *Agastya* who had crossed *Jaladhi* (=ocean). As a number, *Jaladhi* = 10^{14} mahāyojana = 690 light years.

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Some Glimpses from the Vedic Astronomy

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A small treatise on the *Vedāṅga Jyotiṣa*, summarising Lagadha's speculations on astronomy remarks that the Vedas are intent upon prescribing the sacrifices. They are prescribed in the sequential order of time. *Vedāṅga Jyotiṣa* is a science explaining the calendar of sacrifice. Therefore one who knows *Jyotiṣa*, knows the sacrifices [1].

Thus most of the astronomy and consequent astrology has entered in the Vedic literature, through the doors of Vedic i.e. Śrauta Sacrifices.

Let us begin from the Darśa Pūrṇamāsa sacrifices. The term *mās* or *māsa* originally meaning 'the Moon', further denotes the lunar month and also the concept of solar and *Sāvana* months.

Darśa sacrifice is expected to be performed around the conjuction of the *amāvāsyā* and the next *pratipad* day. Pūrṇamāsa sacrifice is expected to be performed around the conjunction of the Pūrṇimā and the next *pratipad* day. The preliminary rites are performed on *Amāvāsyā* or *Pūrṇimā* day and the principal sacrifices are offered at the *Parvan* i.e. the [2] conjunction with the next *Pratipad* day.

It is perhaps in attempt to find out such conjunctions of two (bright and dark) halves of lunar months, the terms like [3] *Anumatī, (pūrvā paurṇamāsī)*; Rākā *(uttarā paurṇamāsī), Sinīvālī (Purvā amāvāsyā)* and *Kūhu (uttarā amāvāsyā)*, came into existence. The term [4] *Kharvikā* refers to *Caturdaśī.* Amāvāsyā and Purṇimā are referred to as [5] *pañcadaśī*, the fifteenth.

Tithi is referred to as *Pratīdṛśyā* in the *Taittirīya Brāhmana* [6]. Bhaṭṭa Bhāskara explains that every day, [7] *Tithi* can be distinctly observed by means of the movements of the Moon. [8] *Ait. Br.* states that, the *amāvāsyā* which covers the sun-rise and the sunset (of the same day) is a befitting *Tithi* for sacrifice. Sāyana here comments that, if [9] *Caturdaśī* or *pratipad* is combined with *amāvāsyā*, between the period of sunrise and sunset (of the same day), the *amāvāsyā* is divided into two days (i.e. it covers two days). Similar is the case with Purṇimā.

The terms [10] *ekāṣṭakā* refer to the *aṣṭamī tithi* while "Udriṣta and Vyaṣṭaka" refer to *Pratipad* of bright and dark half of the lunar month, respectively.

The concept of lunar months, based on *Tithis* involves the accurate knowledge of the exact movements of the Moon. The time required by the Moon, to deviate from the Sun by the rate of twelve degrees is named as *Tithi*. The Vedic astronomers must have known the calculations to that effect.

Since there is no direct mention of the measurements of the movements of Moon or Sun in the Vedic literature, some scholars hold that the Vedic *Tithis* and their names refer only to days and nights in their serial order, in the bright and dark halves of lunar months. But this view is not tenable; under the light of above discussions. Further it may be noted that the concept of *Tithi*, radically differs from that of a *Sāvana* day which is based on the movements of Sun and is calculated from sunrise to sunrise.

That the Moon is overtaken by the Sun on the *Amāvāsyā*-day, was clearly noticed by the Vedic astronomers. This is evidenced by *Ait.Br* (40.5) stating - [12] the Moon enters into the sphere of Sun on the *Amāvāsyā* day. This is further supported by the *Baudhāyana Śrauta-Sūtra*, [13] which explains that if after mid-day, the Moon enters into *Āditya*, on *amāvāsyā* day, it remains so undertaken by the Sun during the latter part of that day and the whole night and upto the middle of the next day. One should perform *darśa* sacrifice around the conjunction of the *Amāvāsyā* and the next *Pratipad*, (which is technically called as Parva).

These references also prove that *Tithi* concept differs from that of a *Sāvana* day.

Normally the lunar year consists of twelve months, at times thirteen; (the thirteenth being the intercalary), but never fourteen. Rudradatta on the [14] Āpśs (12.27.11) confirms that the lunar-year never consists of fourteen months. [15]

After intercalary, I shall deal little later, in this article.

Ṛtus, i.e. the seasons depend on the movements and the positions of the Sun. Therefore the Ṛtu year - (solar year) consists of one complete cycle of Six Ṛtus. Ś.Br (6.7.1.18) states that the year marks its completion by means of the cycle of Ṛtus [16].

In Vedic period, even the [17] names of months were related to Ṛtus. TS 4.4.11 clearly states that a group of two months make one Ṛtu [18].

[19] Ṛg 1.95.3 clearly mentions that the Sun controls the seasons and indicates them distinctly. It may be noted that the names of the months though related to Ṛtus controlled by Sun, denoted the lunar months. This indicates that the Ṛtu (solar) year was linked with the lunar year.

The period from the sunrise to sunrise is named as a *Sāvana* day. This term also owes its coining to the performance of the *Soma*-Sacrifice. [20] Sāyana on T.S suggests that the word Sāvana is suggestive of *ahorātra* (day and night), because in the *Soma*-sacrifice three *sāvanas* i.e. pressing of *Soma*-juice are accomplished during *ahorātra* (TS 5.6.7 - *Triṁśatam rātrir̄ dīkṣitah syāt*). Thus thirty days and nights make one Sāvana month. '*māsam dīkṣitah syāt* in TS 5.6.7' refers to the lunar month.

In the *ayanas* i.e. the yearly *Soma*-sacrifices, the *Ṣaḍahas* - i.e. the units of six-day *Soma* Scarifices are repeated. Thus five *Ṣaḍahas* i.e. five units of Six-day *Soma* sacrifices are performed during one month. They were repeated during all the twelve months of the year. Thus the yearly *Soma*-sacrifices would require three hundred and sixty days (with one additional Viṣuvan day, i.e. 361 days).

Now the lunar month comprises, not thirty days, but broadly about twenty-nine and a half days. The lunar year therefore consists of three hundred and fifty four days.

In the yearly sacrifice (*utsargiṇām ayanam*), TS advises to omit [21] some *Soma*-Sacrifices (after certain period). These ommissions of some *Soma* sacrifices (after appropriate period) were exercised with a view to linking the *Sāvana* year of 361 days with the lunar year of 354 days. Thus six days were adjusted in the *ayana* sacrifice.

Tāṇḍya Br [22] 5.10.2. in this respect explains - if some sacrifices are not ommitted after stipulated period, the lunar year will swell like the leather bag blown with air.

TS (5.6.7) as stated above prescribes to undergo *dīkṣā* either for thirty days or for a month. Here the *dīkṣā* for thirty days refers to a *Sāvana* month and the *diksā* for a month refers to the lunar month [23].

The lunar year is also linked with the Ṛtu (Solar) year by inserting one additional intercalary month, presently known as '*adhika*'.

Ṛgveda (I.25.8) describing the powers of king Varuna, states that Varuna, the upholder of cosmic laws, knows twelve months, along with its days. He also knows the month which is inserted [24] (as an intercalary).

All the *Yajurveda Saṁhitās* give, the list of thirteen or fourteen [25] months, the first twelve being the regular lunar months of a year. The additional two names are *Saṁsarpa* and *Aṁhaspati.*

It is generally maintained by one tradition that *Saṁsarpa* denotes intercalary, i.e. *adhika*, while *Aṁhaspati* is a name given to *Kṣaya-māsa* [26] - i.e. the dropped lunar month. However this view is not tenable.

Muhūrta-cintāmaṇi (I.47) however opines that both the names refer to intercalaries : when, in a year, one month has to be dropped, two intercalaries are to be calculated, the first intercalary is *Saṁsarpa* and the second is *Aṁhaspati* [27]. This view appears to be rational. I see no reason why *Kṣayamāsa*, a month which is dropped, and consequently has no existence, should be given any name.

It is again maintained that the Vedic seers had no knowledge of *Rāśis*, as the names for *Rāśis* are totally wanting in Vedic literature. We shall examine this view in the light of the concept of *Adhika* - the intercalary.

In later literature, we have the clear definition [28] of intercalary. According to them - the intercalary is inserted, when the Sun does not cross the *Rāśi*, during one lunar month, i.e. when crosses only one *Rāśi*, during the period covering more than one lunar month. Thus the insertion of intercalary is related to not-crossing of one *Rāśi*, during one lunar month. It is therefore the consequential inference that if the Vedic astrologers had conceived the intercalary, they must have conceived the *Rāśis* also.

If again the Ṛgvedic astronomers knew the intercalary, they must have known the lapse of lunar month (Kṣaya-māsa) also. If the Sun crosses two *Rāśis*, during one lunar month, one lunar month is dropped. However when one lunar month is dropped, two intercalaries have to be calculated and inserted in that year. In such cases, the first intercalary is *Saṁsarpa* and the second is *Aṁhaspati.*

It may be noted that the concepts of intercalary and that of lapse-month are the devices to link the lunar year with the Ṛtu (solar) year.

I only intend to point out, with the above discussion, that the Vedic astronomers had observed the movements of the Sun and the time required by the Sun to cross the *Rāśis.* Without such observations, they could not have conceived the intercalary month.

Now, while placing Bṛhati bricks, for constructing the fire-altar, *Taittirīya Saṁhitā* (5.3.2) enjoins to place twelve bricks towards south, and further comments -'therefore the months turn southwards' (*tasmād dakṣināvṛto māsāh*).

Bhaṭṭa Bhāskara, the celebrated commentator on TS (5.3.2) remarks - '*meṣādi - samjñā - samñjñita - gola - dvādaśa - bhāga - sthita - divākara - gati - viśeṣātmanām māsānām gola - bhramaṇa - nibandhanāt'* etc., meaning - the solar months are conceived by the unique movements of Sun through the twelve parts of celestial sphere, named '*meṣa*' etc.

Sāyaṇa, the another commentator of TS (5.3.2) remarks- '*dakṣiṇa-dig-vidhānena pradakṣiṇā - vṛttiḥ, sūryasya golaka - pradakṣiṇāvṛttyā niṣpādyamānatvāt caitrādi - māsāḥ dakṣināvṛtaḥ* etc. i.e. the months viz. *Caitra* etc. are conceived by the movements of Sun round the celestial sphere.

I believe that, both the above commentators had deep knowledge of ancient astronomical traditions. Both of them had pointed out the movements of the Sun through the celestial sphere, conceptually divided into twelve parts, later known by the names of *Rāśi.* The period required by the Sun for crossing each twelfth part of the celestial sphere was calculated by months - names as Caitra, Vaiśākha etc. - i.e. the names - Caitra, Vaiśākha etc. originally refer to solar months.

I am inclined to think that [29] *dvādasāram cakram* (Rg I.164.11) or [30] *dvādaśa pradhayah* (Rg I.164.48) perhaps refers to twelve *Rāśi.* Sāyana here actually interpretes - '*dvādaśāram* as *dvādaśa - meṣādi - rāśyātmakaih / māsātmakaiḥ vā araiḥ*' (Ṛg I.164.11).

Maitrāyaṇi Upaniṣad (6.14) belonging to a later period (Pre-Paninian according to Max Müller), states *'sūryo yoniḥ kālasya, tasya etat rūpam - yan nimeṣādi - kālat saṁbhūtam dvādaśātmakam Vatsaram / etasya āgneyam ardham, ardham Vāruṇam / maghādyam Sraviṣṭhārdham āgneyam krameṇa/utkramena Sārpādyam Śraviṣṭhārdham saumyam / tatra ekaikam ātmano navāṃśakam sacāraka-vidham / saukṣmyatvāt etat pramāṇam / etc.*

Probably in the *Maitrāyaṇi Upaniṣad* here, the *Rāśi* is referred to as *navāṁśakam* i.e. 9/4 *nakṣatras.*

The word *Rāśi* in *Chandogya Upaniṣad* 7.1.2, 7.3.1 and 7.7.1 probably refers to the celestial *Rāśi.* According to Grassman, the Ṛgvedic *'rāśayah' (usrā iva rāśayo yajñiyāsaḥ - 8.96.8)* refers to the groups of stars. Pt. S. B. Dixit (P 102) cites a reference from *Baudhāyana-sūtra-viz-'mīna-meṣayor meṣavṛṣabhayor Vasantaḥ'.*

In the *Soma*-sacrifice, two priests, viz. the Adhvaryu and the Pratiprasthātr, offer twelve *Soma*-offerings, with two Ṛtu (season) cups. [i.e. each of them offer six Soma-offerings.] *Taittirīya Saṁhitā* (6.5.3) enjoins that the *Adhvaryu* should approach the *Āhāvaniya* fire, by the south, while the Pratiprasthātṛ, by the north. TS further remarks *'tasmād ādityaḥ ṣaṇmāso dakṣiṇena eti., ṣaḍuttareṇa'* [therefore the Sun goes

to south for six months, to north for six months.] All this suggests that the movements of the Sun cause the Uttarāyana and Dakṣiṇāyana, further giving rise to the concept of the *Devayāna* and the *Pitṛyāṇa*. Cp *ŚBr* 2.1.3 - *Sa (Sūryah) yatra udag āvārtate deveṣu tatra bhavati, yatra dakṣiṇāvartate pitṛṣu tatra bhavati etc.*

The fact that the movements of the Sun cause the lengthening and the shortening of the day, has also been noted by the Vedic seers. The Ṛgvedic poet makes a prayer to Soma-god - '*Soma rājan, pra ṇa āyūṁṣi tāriṣat - ahānīva suryo vāsarāni* (Ṛg 8.48.7) - [O King Soma, do you lengthen our lives, just as the Sun lengthens the bright days in summer].

The middle-most day of the *saṁvatsara* was referred to as a Viṣuvan-day; by the *Aitareya Brāhmaṇa* (18.18) - Cp - *ekavimśam etad ahaḥ upayanti viṣuvantam - madhye samvatsarasya.* Also Cp *Ait Br.* 18.22; *TBr* 1.2.1 *(viṣuvān divākirtyam - yathā Śālāyai pakṣasī evaṁ saṁvatsarasya pakṣasī).*

Viṣuvan means the day, when the day and the night are of equal length. There is no direct reference in the Vedas, to this effect. There are two such days in the year, if a *sattra* sacrifice lasting for one year commences on one of them, the second *Viṣuvan* day may fall in the middle of the *Sattra.*

According to Pt. S. B. Dixit, the words '*pañca* ukṣaṇaḥ' [31] (Ṛg. 1.105.10) or '*Pañca devāḥ*[32] (Ṛg 10.55.3) probably refer to five planets - viz Mars, Mercury, Jupiter, Venus and Saturn.

According to the *Ṛgveda* 4.50.4 and *TBr* 2.8.2 - [33] Bṛhaspati - Jupiter - appears first of all lights, near the Tiṣya (*Puṣya*) constellation. Pt. S. B. Dixit observes that, Tiṣya (*Puṣya*) is one of the six constellations (viz. *Maghā, Puṣya, Viśākhā, Anurādhā, Śatabhiṣak and Revatī*) which can be seen in conjunction with *Bṛhaspati.* It may also be regarded that, *Bṛhaspati* is regarded as a deity presiding over *Tiṣya.*

In *Soma* sacrifice, *Soma* juice is drawn in cups for *Śukra* and *Manthi.* In this context Śatapatha Brāhmana (4.2.1) observes - '*eṣa eva Śukrah ya eṣa tapati - candramā eva manthī*' [that which shines bright is Śukra and the Moon is named as manthī]. *Taittirīya Saṁhitā*, in this context remarks - 'Śukra is the yonder Sun' (TS 6.5.4).

Maitrāyaṇī Upaniṣad (7.1-8) belonging to a little later period refers to Sani, Rāhu, Ketu - rising below (*adhastat udyanti*).

Atharva Veda [34] (19.9.7 - 10) refers to '*divicarā grahāḥ*' (planets moving in sky), the earth-quakes, *Nakṣatram* (constellations), and the comets etc. etc. It also refers to Rāhu [35] along with Moon and Sun, probably suggesting the eclipses. For references to eclipses. vide [36] Ṛg 5.50.5-9, Tāṇḍya Br. 4.5.2, 4.6.13 etc. However, the calculations for predicting eclipses is not found in the early Vedic literature.

Vāj S 30.10 and *TBr* 3.4.1 refer to '*Nakṣatra darśan*'. *Vāj S* 30.20 refers to '*Gaṇaka*' the astronomer. The *Nakṣatras* are referred to by their names, even in the Ṛgveda. But a complete list of the Nakṣatras is given by the *Taittirīya Saṁhitā* (4.4.10) and also by *TBr* (3.1.4-6). Both the lists begin from *kṛttikā* (and not from *Aśvinī*). TBr 3.1.5 refers also to *Abhijit. TBr* 1.5.1-2 and 1.1.2 also refer to the *Naksatras.*

Atharva Veda (19.7) also mentions 28 *Nakṣatras* including *Abhijit.*

Bhatta Bhāskara on *TS* (5.4.1) defines *Naksatras* as - *Vakrānuvakrādi vicitra cāriṇaḥ tāra - grahāḥ nakṣathra - śabdenocyante*; and thus he refers to the movements, such as *vakra, anuvakra* etc. of the stars and planets (*Tārā/grahas*). *TS* 7.5.25 however, differentiates the *Naksatras* from *Tārās.*

The Vedic Ṛsis had observed that some *Nakṣathras* consist of a bunch of stars. Thus, *TS* 4.4.5 had counted the stars of *Kṛttikās* and named them as - *ambā, dulā, nitatni, abhrayanti, meghayanti, varṣayanti and cupuṇikā. TBr* 3.1.4 refers to *Mṛgaśīrṣa*, along with *invakās* - the stars in *Mṛgaśīrṣa. TBr* 3.1.2 suggests that *Śraviṣṭhā* consists of four stars (Cp *Catasro devīhr ajarā Śraviṣṭhaḥ*).

Tāṇḍya Br 1.5.5 appears to refer to *Saptarṣīs* and *ŚBr* 2.1.2.4 states that the Saptarsis were formerly named as *Ṛkṣās* (*Saptarṣīn u ha sma vai purarksā ityācakṣate*).

As Pt. S. B. Diksit states - originally the Nakṣathras may be referring to the divisions of the sky into so many equal parts, and that these parts were suggested by the course of Moon.

The words like - Phalgunī - pūrṇa-māsa, Citrā-pūrṇamāsa, (TS 7.6.8, ŚBr 6.2.2.18, Gopatha Br 6.19 etc.), suggest that the Vedic astronomers had observed the Moon becoming full on the Nakṣathras. [Cp *ŚBr* 6.2.2.18 - *'eṣā ha Saṁvatsarasya prathamā rātriḥ yā phālguni pūrṇamāsī,* or *Gopatha Br. 6.19 - Phalgunyām paurṇamāsyām cāturmāsyāni prayuñjta, mukham vā etat saṃvatsarasya yat phālgunī paurṇamāsī etc.*].

TS 2.3.5 relates a myth that the Moon had a special attachment for Rohiṇī, one of the thirtythree daughters of Prajāpati (twentyseven Nakṣatras + six stars of Kṛttikā). This myth must have come into existence, when the Vedic astronomers observed the close conjunction of Moon with Rohiṇī.

TS 4.4.10 and also 5.4.1 enjoin to place the bricks named Nakṣathreṣṭakās, while constructing the fire altar. On the Southern half of the altar, the bricks represent the *Nakṣatras* - from *Kṛttikā* to *Viśākhā.* On the northern side the bricks represent the *Nakṣatras.* viz. Anurādhā to Apabharaṇī. The placing of the southern bricks begin from east and end towards west, while the placing of the northern bricks begin from the west and end towards the east.

On this placing of bricks, named after *Nakṣatras*, *TS* (5.4.1) remarks - '*purastāt anyāh pratīcīr upadadhāti, paścād anyāh prācīs, tasmāt prācīnāni ca pratīcīnām ca nakṣatrānyāvartante.*' (on the east he puts down some bricks pointing west, on the west, some, pointing east, therefore the constellations move both, west and east' = Keith's Tr.)

Sāyana comments on this passage, as follows - *loképi nakṣatrāni golakasya dakṣinabhāge paścimābhimukhāni, uttarabhāge tu prāṇmukhānītyevam āvartante* etc. Bhatta Bhāskara is more explicit here. He states - '*dakṣiṇa - gole pratīcīnāni, uttarabhāge tu prācīnāni, udayā-nantaram pratīcīnām gatim ārabhante, aṣṭa-manānāntaram prācīnām,* etc. Thus this passage from *TS* 5.4.1, does not only indicate the movements of the Nakṣatras, but their positions after they rise, and after they set up.

Śatapatha Br. 2.1.2 states the - then position of *Kṛttikās* - as follows - *'ekam dve trini catvāri vā anyāni nakṣatrāni, athaitā bhūyiṣṭhā yat Kṛttikāh, tad bhūmānam eva*

etao upaiti, tasmād kruttikāsv ādadhita. etā ha vai prācyai diśo na cyavante [36]. sarvāṇi ha vā anyāni naksatrāni prācyai diśaś cyavante - taṭ prācyām evāsyai tad diśy āhutau bhavataḥ' - amounting to mean that the Krittikās were seen at the east and that they do not leave the east, while other Nakṣatras move away from the east. Pt. S. B. Dixit, on this evidence, infers the date of the Śatapatha Br. as 3100 years before Śaka era.

The Vedic seers maintained that the Moon reflects the light of the Sun - Cp TS 3.4.7 - *'Sūrya - rasmiś candramāḥ'* (the all blessed Sun-rayed *Candramas* - is the Gandharvas - Keith). The Ṛgvedic verse I.84.15 - *'atrāh gor amanvata nāma tvaṣṭuh apīcyam itthā candramaso gṛhe'* is also cited by the scholars to support this view.

The Vedic seers had clear idea that the Sun neither rises not sets. This concept is reflected in the *Ait-Br* 14.6 (*Sa vā eṣa na kadācana astam eti nodeti. tam yad astam etiti manyante'hna eva tad antam itvā, ātmānam viparyasyate. rātrīm evādhastāt kurute ahaḥ purastāt, atha yad enam prātar udetīti manyante, rātrer eva tad antam itvā athātmānam viparyasyate'har evāvastat kurute rātrim parastāt. Sa vā eṣa na kadācana nimrocati.* [The Sun does never set nor rise. When people think, the Sun is setting (it is not so). For after having arrived at the end of the day, it makes itself produce two opposite effects; making night to what is below, and day to what is on the other side. When they believe it rises in the morning, (this supposed rising is thus to be accounted for). Having reached the end of the night, it makes itself produce two opposite effets, making day to what is below and night to what is on the other side. In fact the Sun never sets - Hang.

I have thus tried to examine the Vedic references to *Tithis*, lunar months, solar months, *sāvana* months and years, *Nakṣatras, Rāśis,* the movements of Sun and other ancillary topics in this small article.

References

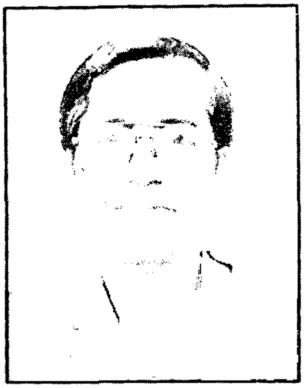
1. Lagadha Jyotisa - 3, *Vedā hi yajñārtham abhi-pravṛttāḥ / kālānupūrvā vihitāśca yajñāḥ || tasmād idam kālavidhāna śāstram | yo jyotisam veda sa veda yajñān ||*
2. Baudhāyana Śrauta-sūtra (24.20) - *etam sandhim abhiyajeta iti.*
3. Ait Br. 7.11 - *yā pūrvā pūrṇamāsī sānumatih, yā uttarā sā rākā, yā pūrvā amāvāsyā sā sinīvālī yā uttarā sā kuhūḥ.*

   Cp Gopatha Br. 6.30, Ṛg. 2.32, Kāthaka Saṁhitā 11.7 ŚBr 6.2.2.18. [Also Amarakosa - *kalāhīne Sānumatiḥ pūrṇe rākā nisākare / Sā dṛṣṭenduḥ sinīvālī sā naṣṭendukalā kuhūḥ ||*
4. Āpśs-24.2.23 *kharvikām tṛtiyām vājasaneyinaḥ Samāmananti |*
5. TBr 1.5.10 - *candrmā vai pañcadaśaḥ, eṣa hi pañcadaśyām āpakṣīyate, pañcadasyām āpūryate.*
6. TBr 3.1.6 - *Sa etam candramaśe pratīdrsyāyai*
7. Bhatta Bhāskara (on TBr 3.1.6) -*Pratidṛsyā tithiḥ · pratidinam candramaso gatyā pṛthaktvena drśyamānatvāt.*
8. Ait Br 32.11 -*yām paryastam iyāt abhyudiyāt sā tithiḥ.*
9. Sāyan on Ait Br. 32.11 - *amāvāsyām paurṇamāsīti vā yām pariprāpya sūryaḥ astam iyāt. Tathā yām abhilakṣya sūrya udiyāt seyam udayāstamayavyāpinī karmopayuktā tithiḥ. Tādṛsyām tithau udayāstamayayoḥ madhye pūrvottarābhyām caturdaśī pratipadbhyām miśraṇe sati dvaividhyam bhavati* ... etc.

10. Tān Br 5.9.1 - *ekāṣṭakāyām dīkṣeran (= Māgha Kṛṣṇāṣṭamī)*
11. Tān Br 18.11.8 - *paurṇmāsyām pūrvam ahaḥ vyaṣṭakāyām uttaram (Vyaṣṭakā = kṛṣna-pratipad) / amāvāsyāyām pūrvam ahaḥ udriṣṭam (udriṣṭa = sukla - pratipad).*

    Cp. Also TBr I.8.10 - *Vyaṣṭakāyām uttaram - - udṛṣṭa uttaram.*
12. Ait Br. 40.5 - *Candramā amāvāsyāyām ādityam anupraviśati.*
13. Baudh *SS' (24.20) Ūrdhvam madhyandināt candramasam ādityo labhate. Sa etam cāparāhnam ca labdho bhavati, sarvām ca rātrim uttarasya cāhṇa ā madhyandināt; etam sandhim abhiyajeta.*
14. (Āps's 12.27.1) - *dvādaśa trayodaśa caturdaśo vā gṛhyante.*
15. *Rudradatta - on Āps's (12.27.1) - Trayodaśa ityadhika-māsābhiprāyam. Uktam ca brāhmaṇe - asti trayodaśo māsa ityāhuh iti. Caturdaśa ityadhika-māsasyaiva avāntara-vikalpābhiprāyam, tau hi kālabhedena tv ādiśyete kālavidbhiḥ. Na tu kadācit api caturdaśa māsāḥ santi samvatsarasya.*
16. *ŚBr 67.1.18 - Ṛtubhir hi samvatsarah śaknoti sthātum.*
17. *TS 1.4.14 - madhuśca mādhāvaśca śukraśca śuciśca nabhaśca nabhasyaśca usaśca ūrjaśca sahaśca sahasyaśca tapaśca tapasyaśca ... upayāma - gṛhito'si samsarpo'si - aṁhaspatyāya tva*
18. *TS 4.4.11 madhuśca mādhavaśca vāsantikāv ṛtū, śukraśca śuciśca graismāv ṛtū, nabhaśca nabhasyaśca vārṣikāv ṛtū, iṣas' corjaśca Śāradāv ṛtū, sahaśca sahasyaśca haimantikāv ṛtū, tapaśca tapaśyas ca śaisirāv ṛtū ...*
19. Rg *1.95.3 - pūrvām anu pradiśam pārthivānām ṛtūn praśāsad vidadhāv anuṣṭhu*
    Cp Sāyana on this verse.
20. Sāyana *(on TS 5.6.7) 'Sāvana-Śabdah ahorātropalakṣakaḥ | Soma-yāge savana-trayasya ahorātra - sampādyatvāt' Cp TS 5.6.7 triṁsatm rātrir dīkṣitaḥ syāt | māsam dīkṣitah syāt.*
21. *TS 7.5.6 - Ṣaḍahaiḥ māsān saṁpādya aharutsṛjanti* - etc. etc.
22. Tāṇḍya Br. *5.10.2 - yathā vai dṛtiḥ ādhmātaḥ evam samvatsaro nusṛṣṭaḥ.*
23. *TS 5.6.7 - Triṁśat rātrīr dīkṣitah syāt – māsaṁ dīkṣitah syāt'* - etc.
24. Rg. (1.25.8) *Veda māso dhṛta-vrataḥ dvādaśa prajāvataḥ/veda ya upajāyate* ||.
25. *TS - (1.4.14) - madhuśca mādhavaśca*
26. Sāyana *on TS 1.4.14 - Cp - kālamādhava* (17) as cited by Sāyana - *asaṅkrāntau ekavarṣe dvau cet samsarpa ādimaḥ / kṣaya - māso dvisankrāntaḥ sa cāṁhaspatisaṁjñakaḥ.*
27. Muhurtacintāmani *I.47* Govinda jyotirvid on Muhūrta Cintāmani - *1.47 - yadā kṣayamāso bhavati tadā pūrvottarau adhimāsau bhavataḥ / Pūrvaḥ Saṁsarpaḥ, dvitīyo -ṁhaspatiḥ.*
28. Vyāsa (as quoted by Pt. S. B. Dixit - p 32) *'Ravinā alaṅghito māsaḥ cāndrah khyāto mali - mlucaḥ' or* Maitreya Sutre *(ibid) - 'māsadvaye yadāpy ekarāśim saṅkrameta ādityaḥ, tatra ādye malimlucaḥ* ||.
29. Rg I.164.11 - *'dvādaśaram na hi taj jarāya, varvarti cakram, pari dyām ṛtasya ā putra agne mithunāso atra saptaśatāni viṁśatiśca tasthuḥ* ||.
30. Rg 1.164.48' *dvādaśa pradhayaḥ cakram ekam triṇi nabhyāni ka u tac ciketa / tasmint sākam triśatā na śankavo'rpitāḥ saṣṭhir na calācalāsaḥ* ||.
31. Rg I.105.10 - *'amī ye pañcokṣaṇo madhye tasthur maho divaḥ | devatrā nu pravācyam sadhrīcīnā nivāvṛtuḥ | vittam me asya rodasī'* ||
32. Rg. 10.55.3 *'ā rodasī aprnādota madhyam pañca devā ṛtuśah sapta sapta / catustriṁśatā purudhā vicaṣṭe sarūpeṇa jyotiṣā vivratena //*
33. Rg. 4.50.4 - *bṛhaspatiḥ prathamam jayamano maho jyotiṣaḥ parame vyoman /* Also T Br 2.8.2
34. AV 19.9.7-10
    utpātāḥ pārthivān takṣā
    Śaṁ no divicarā grahāḥ
    Saṁ no bhūmir vepamānā
    Saṁ ulkānirhatam ca yat /
    naksatram ulka-nihataṁ śam astu /
35. *Śam no grahaḥ cāndramasāḥ*
    Śam ādityāśa rāhuṇā
    Śam no mṛtyur dhūmaketuḥ
    Sam rudrās tigmatejasaḥ ||

36. Rg. 5.50.9. - *'Saṁ vai sūrya svarbhānuḥ tamasā 'vindhyad āsuraḥ / atrayas tam anvavindan na hyanye aśaknuvan.'*
37. Also refer to later Baudh ŚS - 25.5 - *'kṛttikāḥ khalvaitāḥ prācīm diśam na parijahati -* ' |



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Bengali Calendars: The Mounting Mess

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The title contains the word 'calendars'. The use of the plural number is not an oversight here. In fact, it is intentional. In modern days, many societies use more than one calendar. The Gregorian calendar is used in official work almost all over the world. In addition, in any society that is dominantly non-Christian, there is a different calendar which controls the religious and social rituals of that society. The Bengali-speaking people are no exception in this regard. The problem is that, even discounting the Gregorian calendar, there are now more than one Bengali calendars.

I am not talking about different calendars for the Hindu Bengalis and Muslim Bengalis. Of course these are different — very different. The Muslim Bengalis follow the Muslim calendar like all other Muslims in the world. The Christian Bengalis likewise depend on the Gregorian calendar to determine their religious festivals. Bengali-speaking people following other religions follow the calendars appropriate to their religions. The problem that I am talking of pertain to the Hindu Bengalis. It seems that there is no unique calendar for this class of people. We will come back to this issue after a brief discussion of different calendrical systems and a general introduction to the Bengali calendar.

1 Fundamentals of calendar making

1.1 The basic units

A calendar contains days in months, and months in years. There are two basic problems that a calendar maker has to face [1]. The first is to have accurate definitions and estimates of these units of time. First of all, the day is defined to be the period of time between two successive instances of the sun crossing the meridian of any place on the earth. Although this length is not the same always, we can define a *mean solar day* and refer to it as the 'day' in what follows. The *solar year* can be defined to be the period of time that elapses between two vernal equinoxes. According to modern estimates, this definition of the year is equal to 365.2422 mean solar days, neglecting further digits after the decimal point. The definition of month, on the other hand, is inherently lunar. A *synodic month*, defined as the period of time that elapses between two occurrences of full moon, is at an average 29.5309 days long. It has to be remembered that these lengths of the year and the month has been obtained not very long ago, and cruder values were used by calendar-makers earlier.

The second basic problem of calendar making is to accommodate integer number of days into months, and integer number of months into years. With the definition adopted by us, neither the year nor the month contains an integer number of days. The number of months in a year is 12.3681 — not an integer as well. The definition of the year and the month given above are not the only possible ones. But other definitions do not help. There is simply no natural definitions of the day, the month and the year which make the ratios integers.

Different civilizations took different approaches to solve this problem. Accordingly, three basic systems of calendars have evolved. In *solar calendars*, one keeps to the solar years but does not care about the length of the lunar month. This is not to say that there are no 'months' in such calendars. There are. But the beginnings and lengths of these months have nothing to do with the phases of the moon. They are just convenient subdivisions of the year, made in various ways in different solar calendars.

Then there are *lunar calendars*, where the months are truly lunar months. They start typically on the full moon or on the new moon. Twelve such months amount to about 354 days, a period which is called the 'year' in these calendars. In other words, the year has nothing to do with the apparent motion of the sun. It is just a convenient multiple of the month.

The third system gave rise to *lunisolar calendars*. These try not to ignore either the sun or the moon. The months in these calendars are truly lunar months, but there are not necessarily 12 months in a year. Sometimes 12, sometimes 13. Different civilizations have different prescriptions about how to put in the extra month, but the objective is the same, viz., to have the average length of the year same as that of the true solar year.

1.2 Rounding-off and intercalation

No matter which type of calendar one employs, one has to take recourses of some rounding off. The length of the solar year, as we mentioned, is 365.2422 days. However, a solar calendar cannot start a new year exactly 365.2422 days after the beginning of the previous year. If it did, years would have begun at any hour of the day. We would have encountered statements like 'the year such and such will begin next Thursday at 11:25 am'. That does not happen, because we always round things off so that a new year or a new month begins on a new day.

But this brings us to another important feature of a calendar. If you always round off to the nearest integer, you will lose or gain time in your calendar. Take, for example, a solar calendar again. Suppose we decided to have 365 days in a calendar year.

This would be the best approximation to the real value of the solar year. But, if it is used for every year, the calendar would lose about a quarter of a day each year. In 4 years, the loss would amount to about a day, and in about 122 years, we would lose a whole month. Certainly this would not be desirable. So we put in an extra day into the calendar each fourth year. This process is called *intercalation*. Intercalation need not come only in the form of days. In fact, we already mentioned that lunisolar calendars have 12 months in some years and 13 in some others. This can be restated by saying that a normal lunisolar calendar has 12 months, but sometimes an extra month has to be intercalated.

1.3 The dynamics of a calendar

So these are the elements which define the dynamics of a calendar:

1. A calendrical system — i.e., a decision about whether the calendar should be solar or lunar or lunisolar.
2. The ratios of different time scales in that system, e.g., how many days are there in a year.
3. A method of rounding off.
4. An algorithm for intercalation.

Since we are very much used to the Gregorian calendar, we might think that these four steps are related, but in principle they are not. In fact, two systems can disagree on any one or more of the issues above even if they agree on all others. To appreciate this point, let us consider in what ways can another solar calendar be different from the Gregorian calendar. The length of the year that we have quoted comes from modern scientific measurements. But these were not available for a long time. Different civilizations determined the length of the year and found answers which differ a little bit from one another. The Julian calendar, the precursor of the Gregorian calendar, estimated the length of the year to be exactly 365.25 days, and therefore a day had to be intercalated once every 4 years. By the 16th century, it became clear that this calendar was not in phase with the change of the seasons. A new evaluation of the length of the year was needed, which was done at that time. Based on that, the Gregorian calendar was established, which treats the years ending with '00' in a different way than the Julian calendars. Years like 1700, 1800, 1900 which are not exactly divisible by 400 would have been leap years in the Julian system, but not in the Gregorian system. Thus there are 97 leap years in a cycle of 400 years in the Gregorian calendar, which makes the average length of a calendrical year to be 365.2425 days. This is different from that of the Julian calendar, but note that this is also not perfect. This calendar is also getting out of phase with the real solar year by 0.0003 days per year.

However, even if we agree on the average length of a calendar year, we can round off differently. In the Gregorian calendar, 'normal' years are always rounded off to the

largest integer number of days which is smaller than the real length of the year, i.e., 365. This need not be the only way. For example, we could have taken a system in which a 'normal' year is rounded off to the smallest integer number of days which is larger than the real length of the year, i.e., 366, and taken 3 days off the year every fourth year and another extra day off for every year divisible by 400. That would have yielded exactly the same average length of a calendrical year over a cycle of 400 years.

And finally, it has to be realized that even if we follow the definition of the 'normal' year as 365 days, we need not intercalate a day every fourth year. We could have intercalated 2 days every eight years, for example. Another way, employed in some calendars, is the following. You keep track of when the real year begins, keeping fractions of days into account. If this happens to begin after the noon time, you start the calendar year a day later. But if the real year begins before noon on a certain day, that day is the new year's day on the calendar. In fact, similar criteria are employed for determining the beginning of a calendrical month in most lunar and lunisolar calendars.

1.4 Other features of a calendar

The features mentioned above can be, and has been, called the "dynamical features". These determine how the calendar keeps track of different natural units, viz., the year, the month and the day. There are other features in which two calendars can differ from one another. These can be called the "initiation features". For example, suppose we keep all other features of the Gregorian calendar intact, but decide that the years should begin on the 1st of March. Or suppose we decide that we count our years, not starting with the calculated birth date of Jesus Christ some 2000 years ago, but with the birth date of Isaac Newton. In that case, the year 2000 of the Christian era would then be called the year 359 in the Newtonian era, and so on. But these are more like features of tag and not of the essential functioning of the calendar. The mathematically minded reader might like an analogy — these are like the initial values specified for a differential equation, whereas the dynamical features are the differential equations themselves. While these features are somewhat secondary ones in the structure of a calendar, we will later see that they can bear important information nevertheless about the dynamics as well.

2 The structure of the Bengali calendar

One can ask, where does the Bengali calendar fall within these categories mentioned above? And the answer reveals the first dichotomy of the Bengali calendar.

As far as the day reckoning is concerned, Bengali calendar is solar. Not only does the length of the year attempt to correspond to the solar year, but the months in this calendar are also defined to have some relation with the apparent motion of the sun. Over the year, the sun moves relative to the earth in a cyclic path called the *zodiac*. The entire closed path subtends an angle of 360°. It can be divided into twelve equal angles of 30° each. Months in the Bengali calendar correspond to the passage of each of these twelve equal divisions.

This is not to say that the Bengali months all have equal length. We know that the earth moves around the sun in an elliptical orbit, not a circular one. Thus, the time required to cross an angle of 30° is largest when the earth is furthest from the sun, and smallest when the earth is closest to the sun. Indeed, the Bengali month of "Poush" typically has 29 to 30 days since it occurs when the sun-earth distance happens to be the least — in December-January. On the other hand, the months of "Joishtho" or "Asharh", which are about half a cycle apart, can have even 32 days.

This is a characteristic which is not present even in the Gregorian calendar. In the Gregorian calendar, the months are only some arbitrary sub-divisions of the year. The months in the Bengali calendar, on the other hand, are not really arbitrary, as we see. So, in this sense, the Bengali calendar is even more solar than the Gregorian calendar.

That's nice, but that's not the end of the story. All the religious festivals of the Hindus are determined by the lunisolar calendars which are prevalent in northern and western India. Most of these festivals occur on fixed dates in the lunisolar calendars. When translated to the solar Bengali calendar, they look chaotic as a result. Before the beginning of the Bengali year, most Bengalis spend some anxious time guessing what would be the dates of Durga Puja in the coming year. They have no way of guessing it until they see the calendars for the new year, because they don't know about the undercurrent of the lunisolar calendar which determine them.

The confusion is made worse by the fact that the names of the months are the same in both calendars. The lunisolar calendar, like its solar counterpart, has the same month-names as those given in Table 1. Thus, an average Bengali Hindu knows that Durga Puja should occur during the bright fortnight *("Šukla Pakshȧ")* of the month of Ashwin. And yet quite often he or she finds that the actual dates of the Puja fall in the following month of Kartik. This happens about once in three years, because of the intercalation of a month in the lunisolar calendar, which shifts all dates with respect to the dates of a solar calendar. But this is something that the average Bengali Hindu does not have a cause or a chance to know, and therefore gets understandably perplexed.

Take, for example, the dates of the Durga Puja that fell in the Gregorian year of 1999. The last day of the festival, i.e., *Dashomi*, which is called *Dusserah* in Northern

India, fell on 20th October. In the Bengali solar calendar it corresponded to the 2nd of Kartik.

We have already explained the reason for the phenomenon. In that year, the North Indian lunar calendars had their beginning of the month of Boishakh on the 1st of April. The next month, called Joishtho in Bengali, started on the 1st of May in the lunisolar calendars after the full moon day. The next full moon was on the 30th of May, but Āshārh did not start the day after. An extra month was introduced at this point, which would be called "adhik Joishtho" (which literally means "extra Joishtho"). The month of Āshārh started after the completion of this extra month, viz. on the 29th of June. The months in the solar calendar, however, did not stop ticking meanwhile, so the lunisolar Āshārh appeared late by about a month compared to the solar Āshārh. And Durga Puja fell back by about a month in the solar calendar.

I am saying "about a month", because that's what it is. It is not exactly a month. The reason is that the lengths of the months are not the same in the lunisolar and the solar calendars, as discussed earlier. So there is always some mismatch, which essentially accumulates to grow as big as about a month, when again the lunisolar calendar intercalates an extra month.

3 Rounding off in Bengali calendars

The dichotomy described above is common to all Bengali calendars. In fact, it is even an important part of them. But even then, there are other features in which calendars differ from one another.

One of these concerns the rounding off rules. There are various *panjikās*, or almanacs, that appear with the calculation of the Bengali months and days. They do not usually explain their methods of rounding off. However, it is clear the rules are different for different panjikās because the months do not begin and end at the same times in all of them. To illustrate this, in Table 1 we present the months as they appear in two Bengali panjikās for the Bengali year 1407, which started in mid-April of the Gregorian year 2000. As we see from the table, among the twelve months there are six whose lengths are different in the two panjikās. For all practical purposes, then, these two panjikās represent two different calendars, because they group days into months in different ways. The Bengali calendar makers have not been able to reach an agreement about these rounding off rules.

Such disagreements, for solar or for lunar months, become touchy when they occur for the months of major festivals like the Durga Puja. Situations are not infrequent when the dates for the Durga Puja differ according to different panjikās. In principle, it is also not inconceivable that the number of days in a particular year would be

Table 1. Names of the months in Bengali calendar, trasliterated roughly according to their Bengali pronunciation. For the year 1407 in the Bengali era, we show the Gregorian date of the beginning of each month as well as the number of days in each month according to two panjikās.

Month name	In BSP (Ref. [2])		In PMBP (Ref. [3])	
	Starts on	Length	Starts on	Length
Boishākh	14/ 4/2000	31	14/ 4/2000	31
Joishtho	15/ 5/2000	31	15/ 5/2000	32
Āshārh	15/ 6/2000	32	16/ 6/2000	31
Srābon	17/ 7/2000	31	17/ 7/2000	32
Bhādro	17/ 8/2000	31	18/ 8/2000	31
Āshwin	17/ 9/2000	31	18/ 9/2000	30
Kārtik	18/10/2000	30	18/10/2000	30
Aghrān	17/11/2000	29	17/11/2000	30
Poush	16/12/2000	30	17/12/2000	29
Māgh	15/ 1/2001	29	15/ 1/2001	29
Phālgun	13/ 2/2001	30	13/ 2/2001	30
Choitro	15/ 3/2001	30	15/ 3/2001	30
		365		365

different according to different panjikās. If the month of Āshārh can start on different days, there is no reason why the month of Boishākh cannot. However, I do not have enough collection of panjikās to verify whether this has actually happened in recent times. But I will be surprised if it has not.

4 The year in Bengali calendars

Let us now look again at Table 1 and discuss one feature in which, at least for the year shown, there is no disagreement between the two panjikās. This is the beginning of the Bengali year. As we see, it starts on the 14th of April. The question is, why?

This may not sound like a meaningful question at first. The beginning of the year ranks among the initiation features that we described earlier. Anyone can 'start' a year whenever one wants. If the Bengali calendar starts it on the 14th of April, why does one need a reason or a justification for that?

The answer to this question is the following. The Bengali calendar certainly has a rule to start its New Year. That rule has to be given irrespective of any other calendar. In other words, the Bengali calendar makers must not have agreed that they will start the new year on the 14th day of the 4th month of the Gregorian calendar of each year.

So, how do they define the beginning of their new year? That, to be precise, is the question.

Most old civilizations started their year at the time of the year when winter ended and spring began. The Gregorian calendar or its precursor, the Julian calendar, are examples where this was not the case — the year started in the middle of the winter. But before the modifications introduced by Julius Caesar, the Roman calendar also started the year in March, which roughly corresponds to the beginning of spring. The names of the months still bear testimony to this rule — the seventh month was September, the eighth October, etc. because 'seven' was 'septem' in Latin, and 'eight' was 'octo'. Among the calendars which survive to this day, the Chinese and the Jewish calendars — both lunisolar — still start their year some time around March. The Persian solar calendar starts its years on the vernal equinox. So why does the year start in mid-April in Bengali calendars? Or, to phrase it in a different way, what marks the beginning of the Bengali new year? The answer to this question sheds important light on the dynamics of Bengali calendars.

The Bengali calendar makers do not use the length of the year that we have quoted so far in this article. One of the panjikās, the *Bishuddha-Siddhānta Panjikā*, clearly says that the length of the year used by them is [6] "365 days 6 hours 9 minutes 9.8 seconds", i.e., 365.25636 days roughly. This, indeed, is the length of the *sidereal year*. But for calendrical purposes, the more relevant measure is that of the *equinoctical year*, i.e., the time difference between two successive vernal equinoxes. Its importance derives from the fact that the differences between different seasons are determined by it. It is this measure of the year that we have quoted earlier in this article. The two measures are not the same because of the precession of the axis of the earth, which is called *ayan-gati* in Sanskrit texts on Astronomy. Thus, the sidereal year is called the *nirayan barsha*, i.e., the year without *ayan-gati* being taken into account.

The difference between the sidereal year and the equinoctical year therefore amounts to 0.01416 days roughly, i.e., of 20 minutes and 23.4 seconds. This may not sound like a large error for a year, but if the calendar has to function for centuries, such errors accumulate. So, if this measure of the year had been used in the Bengali calendars since the time of the *Surya-Siddhānta*, i.e., for about 1400 years, the calendar would have gotten out of phase with the seasons by about 20 days, 19.8 to be more precise.

The real mismatch is worse. In the above estimate, I used the value of the year adopted by the *Bishuddha-Siddhānta Panjikā*, which is the length of the sidereal year according to the recent astronomical measurements. They wanted to use this *bishuddha*, or accurate, estimate over that of the *Surya-Siddhānta*. According to the latter, the length of the year was 365.258756 days, i.e, 365 days 6 hours 12 minutes and 48 seconds. Since this was the measure used for most of the time in history, the difference accumulated has been larger. It is, in fact, a little larger than 23 days. And if you go back 23 days from the Bengali new year's day, you get the day of the vernal equinox. In other words, the beginning of the year was fixed to be at the vernal equinox sometime around 6th century A.D. But the dynamics was not right, so the calendar fell out of phase with the seasons. Right now, the new year's day has shifted

by about 23 days. And if the length of the year is kept fixed at the value suggested by the *Surya-Siddhānta*, the calendar will continue to lose an extra day every sixty years or so. If instead we use the *Bishuddha-Siddhānta* value, the results will be marginally better, because the loss of an extra day will occur roughly every 70 years.

This mismatch is already apparent in some important ways. Rabindranath Tagore's birthday, the 25th of Boishakh, is celebrated every year throughout Bengal with a lot of enthusiasm. According to his biographers [4], he was born on the 7th of May at 2:28 am, in the Christian year of 1861. Conventionally, a new 'day' starts at midnight in the Christian calendar. In Bengali as well as most other Indian calendars, the new day starts at sunrise. Thus, Rabindranath was born in the night between the 6th and the 7th of May. The new day had not yet started then in the Bengali system, so the hour of his birth fell within the 25th of Boishakh. From sunrise to midnight, 25th of Boishakh corresponded to the 6th of May in that year.

It means that in 1861, the Bengali new year must have started on the 12th of April. In modern times, the Bengali new year falls either on the 14th or on the 15th of April, depending on the methods of rounding off. But it **never** falls on the 12th of April. The mismatch has grown by at least two days in the 140 years since Rabindranath was born.

And this is not all. On this matter as well, there is no unanimity among the Bengali calendar makers. Although the *Bishuddha-Siddhānta* panjikā uses the modern value of the sidereal year, the other panjikās don't. To take an example, I consider the other panjikā that I have, called P. M. Bakchi'r Directory Panjikā [3]. It does not announce the length of their year directly, but it tells how to calculate the amount of precession of the equinoxes. Their formula is the following. Suppose ϕ is the precession angle, measured in degrees, in the year y of the Saka era. Then [5]

$$\phi = \frac{0.9}{60} \times (y - 421)\,.$$

This means that a full precession of 360 degrees takes 24000 years. In other words, the length of the year that they employ differs from the equinoctical year by 1/24000 fraction of a year, or by 21 minutes and 54.87 seconds. So the length of the year that they employ is 365.25742 days. This is not the value given in *Surya-Siddhānta.* More importantly, this is different from the value used by *Bishuddha-Siddhānta.* So, even these two panjikās will be out of phase in the future in predicting days. The only little consolation is that the difference is small, and a difference of a full day will accumulate in about 950 years. But by that time, the mismatch between either of these panjikās with a true equinoctical calendar will come to much more than a month, so probably both will become useless by that time.

5 The enigma

I have no intention of implying that the Bengali calendar makers do not know about these mismatches that I talked about. Certainly they know that the *Surya-Siddhānta*

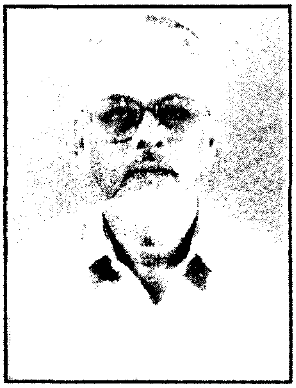
was not infallible. They know about later work done in India, trying to improve the estimates of *Surya-Siddhānta*. Even in the 19th century A.D., there were observations by Samanta Chandra Sekhar [7], analysis by Sankara Balakrishna Dikshit [8], trying to find the improvements of the ancient determinations of various basic units that mark a calendar. The more precise, modern astronomical values of these units must also be known to the calendar makers. Certainly they know that the Government of India had set up a 'Calendar Reform Committee' in 1955, under the leadership of Meghnad Saha, to look into the problems of Indian calendars and to rectify them. The report of this committee [9] produced a calendar where the length of a year is the true equinoctical one. This system is now being used for more than forty years to construct what is called the *Rashtriya*, or National, calendar. And no one can make me believe that the Bengali calendar makers are unaware of all these developments.

And yet, they stick to the *nirayan barsha* and letting the Bengali calendar slip out of phase with the seasons. I don't understand why. Is it just some weird notion of 'loyalty' to the *Surya-Siddhānta*?

I am very happy to dedicate this article to the memory of great Indian astronomer Samanta Chandra Sekhar.

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The Starry Messenger

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The person who really turned the tide against the Aristotelian world centered around the Earth in favour of the Copernican world was Galileo Galilei. He was born at Pisa on 15^{th} February, 1564. He used a combination of mathematics, logic and brilliant observational techniques, and laid the foundations of modern science. The instrument he used most effectively was the telescope which had already been invented in Holland. He heard about it and was quick to realize the principles on which it was based. He built one himself which was eight to ten times more powerful, and put it to use not only to watch out for distant ships approaching Venice but, most importantly for science, to watch the sky. And for the first time the heavenly bodies started yielding their secrets to Man from the hidden depths of space.

He was the first man to behold the face of the Moon as it was. He was surprised to find it was not a perfectly smooth Aristotelian sphere at all. Its face looked much like our Earth, with mountains and craters, but no vegetation - a dusty, rocky, forlorn world. He even made wash drawings of the Moon's cratered surface. Next he turned towards Jupiter and was both astonished and delighted to find it had four moons that revolved round it so fast he could actually see them go behind it and emerge from the opposite side in a matter of hours. Here then was real evidence that not everything in the heavens moved around the Earth – there were other centres of revolution in the universe too, like Jupiter.

The third remarkable thing he observed were the phases of the planet Venus, waxing and waning much like the phases of our Moon. He also observed that it looked much larger in its crescent phase than when it was almost full. This, Galileo argued, could be easily explained if Venus orbited the Sun rather than the Earth, and was between the Sun and the Earth. Then an astronomer on Earth would be able to see its fully lit face when it is on the far side of the Sun and only its crescent face when nearer the Earth.

The most surprising observation was the stars. It was clear that they were not studded on the inner surface of an Aristotelian sphere but were spread out into the depths of space that was much vaster than anybody could have imagined. Moreover, the stars were not uniformly spread out through space but were organized into groups or galaxies, the most impressive of which was the Milky Way. He wrote:

I have observed the nature and material of the Milky Way... The galaxy is, in fact, nothing but a congeries of innumerable stars grouped together in clusters. Upon whatever part of it the telescope is directed, a vast crowd of stars is immediately

presented to view. Many of them are rather large and quite bright, while the number of smaller ones is quite beyond calculation.

All this was strong observational evidence that we do indeed live in a Copernican solar system in a gigantic world. The impact of these discoveries on the public mind was sensational. Watching the heavens through the telescope came into vogue. Galileo published his observations in his famous book *The Starry Messenger* which was an instant success. Its reputation reached lands as far away as China.

Galileo immediately realized that there was a conflict between the science of his day and the reality of a moving Earth. As we have seen, the most influential thinker of the early days in Europe was Aristotle. His cosmology was based on two cardinal assumptions. First, the Earth was the natural fixed centre of the whole universe. And second, motion in the heavens and motion on Earth followed entirely different laws. When we see something at rest, we do not normally ask, why is it at rest? It seems quite natural for a body to be at rest. But when we see something moving, like a football that has been kicked, we immediately say to ourselves, someone must have kicked it. So it was quite sensible for Aristotle to say that the Earth did not move, for everyone directly experiences it to be stationary. This is a perfectly sensible way of looking at things. But then, what makes the crystal spheres move round the Earth? Divine intervention must be involved, and their motions were therefore thought to be entirely different from terrestrial motion. This was the Aristotelian physics and cosmology that was prevalent in Europe until the 16^{th} century.

In 1632 Galileo published his famous *Dialogue of the Two Chief World Systems* in which Salviati, a Copernican and a thinly disguised Galileo discusses the merits of the Copernican and the Ptolemaic systems with two other characters, Simplicio, an Aristotelian and Sagredo, an independent who was open to persuasion. In spite of the superiority of the Copernican system over the Ptolemaic system, every critic of Copernicus had pointed out that the motion of the Earth was blatantly contradicted by everyday experience. As Simplicio says in the *Dialogue*, the crucial thing is being able to move the Earth without causing 'a thousand inconveniences'. If day and night were really caused by the rotation of the Earth around its axis, why was there not a 'thousand inconveniences' like an easterly storm blowing across the face of the Earth all the time? In India, long before Copernicus, Āryabhata had to face a similar objection from the Indian pundits when he proposed that the Earth's rotation round its axis was responsible for day and night. The pundits had pointed out that birds, which fly away from their nests early in the morning in search of food, would surely not be able to find their nests in the evenings had the Earth really moved away beneath them! Āryabhata failed to give a satisfactory answer to his critics.

It was Galileo who first came forward with an answer that was almost convincing. He realized that in order to defend Copernicus, he had to prove that the Earth could move without causing 'a thousand inconveniences'. But to do that he had first to challenge and disprove Aristotle's physics and cosmology. He argued forcefully in favour of a unity of motion in the sky and on Earth and against the Aristotelian dichotomy. He contended that the debate as to whether the Earth moved or not

could only be settled by examining what happened in moving bodies like carriages and boats. Mechanical experiments here on Earth could give us valuable information about motion in the sky.

Aristotle believed that heavier bodies fell faster than lighter ones in a given medium. He also assumed, and quite justifiably, that the less dense the medium, the faster would a body fall through it. From this he concluded, quite wrongly though, that a body would fall infinitely fast in a perfect vacuum. Since an infinite speed was impossible, he argued against the very possibility of motion through a perfect vacuum. Galileo was suspicious of Aristotle's ideas from childhood. As a boy he had seen many hailstorms in Italy. He had noticed that stones of various sizes and weights came down more or less together. Assuming that they were formed more or less at the same time and at the same height above the ground, the heavier ones should have reached the ground earlier than the lighter ones if Aristotle was right. The story goes that Galileo actually contradicted Aristotle by dropping balls of different weights from the Leaning Tower of Pisa in the presence of astounded scholars. The story is only apocryphal. Had Galileo actually done this experiment, he would have found the heavier weights come down slightly faster than the lighter ones because of air resistance. Most importantly, Galileo did not have clocks to measure accurately the time it took the balls to fall.

The pendulum played a crucial role in Galileo's scientific thinking. By using his own pulses, he carefully measured the time taken by a pendulum to complete one swing. He was astonished to find that this time did not depend on the size of the arc through which the pendulum swung, as long as the arcs were not too large. How could the pendulum adjust its speed so as to return through shorter and shorter distances as its motion died down, wondered Galileo in amazement. The ideas about downward acceleration of a body and the continuation of motion once acquired slowly began to dawn on him.

Galileo believed in making precise measurements. But he found that the vertical fall of a body was too rapid to allow precise measurement of the times taken by it to cover various distances. So he came up with a brilliant idea - slow down the fall by making the body roll down an inclined plane. This gave him ample time to observe and measure. He experimented with polished balls of different materials and a smooth plane whose inclination he could alter. He measured the time taken by a ball to roll down different distances along the plane.

He wrote: " Repeated a full hundred times we always found that the spaces traversed were to each other as the square of the time." This was true of all the balls he used, in flat contradiction with Aristotle's idea that heavier balls fell faster. He slowly began to understand what he had seen of hailstones as a boy- he had discovered the famous law of falling bodies, namely that all bodies of all shapes, sizes and weights fall equally fast in a perfect vacuum.

He also varied the angle of inclination of the plane and drew the following conclusions. When the plane is vertical, the ball falls freely. When the plane is horizontal and the ball is set rolling, it goes farther the smoother the ball and the plane. From

this he concluded that it would roll with constant speed forever in the total absence of friction! It would not require any external agent to keep it moving! On the contrary, friction with the plane was necessary to *stop* its motion. He had discovered the law of *inertia of motion* that was to become one of the cornerstones of Newton's physics. Galileo had turned the table round in complete defiance of Aristotle.

But what about the motion of the Earth without causing 'a thousand inconveniences'? This is how he argued. Suppose you are aboard a ship at mid sea from where no coastline is visible, and it is moving *uniformly* without any jerks. You cannot tell that it is moving unless you look at the water. Suppose a ball is released from the top of the ship's mast. You would see it fall down at the bottom of the mast, just *as if* the ship were at rest. Thus, Galileo argued, if the Earth moved *uniformly* through a perfect vacuum, we would not feel its motion. This certainly made it possible that the earth *could* be in motion without causing 'a thousand inconveniences', but it did not *prove* that it *was* in motion.

He made a mistake. To him only circular motion was possible. He wrote in his *Dialogue:* "It seems to me one may reasonably conclude that for the maintenance of perfect order among the parts of the universe, it is necessary to say that movable bodies are movable only circularly; if there are any that do not move circularly, these are necessarily immovable, nothing but rest and circular motion being suitable to the preservation of order."

Even falling bodies, according to him, moved in circular paths by natural tendency. But, as he was quick to point out, the difference between straight lines and vast circular arcs was imperceptible. Only in this way he could bring unity to motion in the sky and on Earth and refute Aristotle. To him the burning question was, how to establish the essence of the Copernican system in which the planets moved in circles round the Sun. Merely replacing circles by ellipses proved nothing, in his view.

He therefore dismissed Kepler's elliptic orbits as fantasy. To this extent his astronomy ignored the finer details of planetary motion discovered by Kepler. He was, of course, also wrong in his belief that only circular motion could be uniform. He, too, could not free himself from the Greek concept of the beauty and symmetry of spheres and circles. He also had a wrong theory of the tides that, according to him, were caused by the rotation of the Earth about its axis. His adversaries also dismissed his telescope as a toy that produced illusion rather than magnification. This was actually not unreasonable because Galileo's early telescope produced such dim images in so narrow a field of view and with such spurious colours that it was not obvious at all that it did magnify. As a result of all this, people remained skeptical of his claims.

In the beginning he faced less opposition from the Church than from the pedants. However, he became vain, and carried away by his zeal, he started to claim that he could actually *prove* the Copernican system to be correct, which he could not. He offered no causal explanations but only analogies. That was the essential weakness in his arguments. He nevertheless started to ridicule the anti-Copernicans at every possible opportunity. In the end he brought himself to an indefensible position by advancing his wrong theory of the tides as proof of the Copernican system. This proved to be

his Achilles heel. Although Kepler had a better theory, Galileo ignored it completely. He was warned by his friends not to press it too far, but he did not listen. In the end the Church declared the Copernican view contrary to the Scriptures and banned *De Revolutionibus*. Kepler was furious. 'Some through their imprudent behaviour, have brought things to such a point that the reading of the work of Copernicus, which remained absolutely free for eight years, is now prohibited', he complained. In the end even his friends within the Church decided to dump him as a troublesome old man. He was ordered to appear before an Inquisition in Rome. There was no debate on the correctness of the scientific views he held. The point was one of obedience to the Church. A false charge was brought against him through forged 'minutes' of his meeting with Cardinal Bellarmine (a friend of his who had died by then) in 1616 according to which he had been enjoined from holding, teaching or defending Copernicanism in any way, even as a hypothesis. Defenceless, and threatened with physical torture at the age of seventy, he finally gave up. On June 22, 1633 he recanted his heresies on his knees in the great hall of the Dominican convent of Santa Maria Sopre Minera in the following words that were prescribed by the Church:

Wishing to remove from the minds of your Eminences and of every true Christian this vehement suspicion cast upon me, with sincere heart and unfeigned faith I abjure, damn, and detest the said error, heresy, and sect contrary to the Holy Church; and I do swear for the future that I shall never again speak or assert, orally or in writing, such things as might bring me under similar suspicion. . .

This trial and censorship drew more attention to his ideas than might otherwise have been the case. Galileo spent the rest of his life under house arrest in his villa outside Florence where he wrote his famous book *Dialogues Concerning Two New Sciences*, a treatise on motion and inertia. He became blind in 1637 and died in 1642, the year Newton was born in England. His books, written not in Latin as was the custom in those days but in lucid Italian, were smuggled out of Italy and published in Holland and France where they became very popular. The spirit of freedom of scientific enquiry spread to northern Europe. Galileo became the leading light. Italy was the loser in the end.



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Motivations for Grand Unification and Its Current Status

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1 Preamble

It is a pleasure for me to write this article in honor of the memory of Samata Chandra Sekhar, a self-made pioneer astronomer of the nineteenth century, who hailed from the state of Orissa in India. Given his isolation and the rudimentary nature of the devices which he had to use for his studies, and yet the accuracy of his observations and predictions [1], his scientific abilities and spirit, I believe, rank among the highest in the class. In this respect, it seems to me that his talents have not received even nearly the recognition that they justly deserve. Samanta Chandra Sekhar dealt with the world of the very large. It has become clear in recent times, however, that the very large and the very small are intimately connected. The evolution of the universe over a period of some fifteen billion years, from the instant of the Big Bang until now, depends crucially on the laws of the microscopic physics- i.e., physics that operates at distances as short as 10^{-30} to 10^{-33} cm. In particular, the idea of inflation which addresses the so called horizon and the flatness problems, and that of baryogenesis, which attempts to explain why we see around us only baryons and not anti-baryons, may have a lot to do with the concept of grand unification, which proposes an underlying unity of the strong, electromagnetic and weak gauge forces. In honor of Samata Chandra Sekhar's memory, and in line with my own interest therefore I would like to say a few words about the concept of grand unification – the motivations which led to this idea - and its current status.

2 Why Grand Unification

To set the background, let me begin by saying that the standard model of particle physics, based on the gauge symmetry $SU(2)_L \times U(1)_Y \times SU(3)_C$ [2, 3] is found to be in excellent agreement with observations, at least up to energies of order 100 GeV. Its success in turn constitutes a triumph of quantum field theory, especially of the notions of gauge invariance, spontaneous symmetry breaking, and renormalizability. The next step in the unification-ladder is associated with the concept of "grand unification", which proposes a unity of quarks and leptons, and simultaneously of their three basic forces: weak, electromagnetic and strong [4–6]. This concept was introduced on purely aesthetic grounds, in fact *before* any of the empirical successes of the standard model

was in place. It was realized in 1972 that the standard model judged on aesthetic merits has some major shortcomings [4, 5]. For example, it puts members of a family into five scattered multiplets, assigning rather peculiar hyper-charge quantum numbers to each of them, without however providing a compelling reason for doing so. It also does not provide a fundamental reason for the quantization of electric charge, and it does not explain why the electron and proton possess exactly equal but opposite charges. Nor does it explain the co-existence of quarks and leptons, and that of the three gauge forces - weak, electromagnetic and strong - with their differing strengths.

The idea of grand unification was postulated precisely to remove these shortcomings. It introduces the notion that quarks and leptons are members of one family, linked together by a symmetry group G, and that the weak, electromagnetic and strong interactions are aspects of one force, generated by gauging this symmetry G. The group G of course inevitably contains the standard model symmetry $G(213) = SU(2)_L \times U(1)_Y \times SU(3)_C$ as a subgroup. Within this picture, the observed differences between quarks and leptons and those between the three gauge forces are assumed to be low-energy phenomena that arise through a spontaneous breaking of the unification symmetry G to the standard model symmetry G(213), at a very high energy scale $M \gg 1TeV$. As a *prediction* of the hypothesis, such differences must then disappear and the true unity of quarks and leptons, and that of the three gauge forces, should manifest at energies exceeding the scale M.

The second and perhaps the most dramatic prediction of grand unification is proton decay. This important process, which would provide the window to view physics at truly short distances ($< 10^{-30}$ cm), is yet to be seen. Nevertheless, as I will list below, there has appeared over the years an impressive set of facts, which provide strong evidence in favor of supersymmetric grand unification, especially that based on the gauge symmetry SO(10) or a string derived $G(224) = SU(2)_L \times SU(2)_R \times SU(4)^C$ symmetry. The evidence includes:

(i) The observed family multiplet structure : This is the fact that all fifteen members of a family neatly become parts of a whole (*one multiplet*) under the symmetry G(224) [4] (subject to left-right discrete symmetry) or SO(10) [7], with their weak hyper-charges predicted precisely as observed. It is hard to believe that this feature is just an accident. The G(224) symmetry (or SO(10)) introduces some additional attractive features, including especially the right-handed (RH) neutrinos (ν_R's) accompanying the left-handed ones (ν_L's), and *B-L* as a local symmetry. Both of these features now seem to be needed on empirical grounds.

(ii) Quantization of Electric Charge and Q(proton)=-Q(electron) : Grand unification provides a compelling reason for both the facts.

(iii) Meeting of the three gauge couplings : Such a meeting is found to occur at a scale $M_X \approx 2 \times 10^{16}$ GeV, when the three gauge couplings are extrapolated from their values measured at LEP to higher energies, in the context of supersymmetry[8].

This is a strong evidence in favor of both grand unification and supersymmetry[9]. These in turn may well emerge from a string theory[10] or M-theory[11].

(iv) Mass of $\nu_\tau \sim 1/20$ eV : Subject to the well-motivated assumption of hierarchical neutrino masses, the recent discovery of atmospheric neutrino-oscillation at SuperKamiokande [12] suggests a value for $m(\nu_\tau) \sim 1/20$ eV. This value goes extremely well with SUSY unification based on $SO(10)$ or a string-derived $G(224)$-symmetry [13]. This is because $SU(4)$-color symmetry contained in $G(224)$ and thus in $SO(10)$ relates the Dirac mass of the tau neutrino to the top mass at the unification scale, yielding $m(\nu^\tau_{Dirac}) \approx m_t(M_X) \approx 120$ GeV; while SUSY unification, using minimal Higgs multiplets, naturally leads to a Majorana mass of the RH tau-neutrino given by $M(\nu^\tau_R) \approx 4 \times 10^{14} GeV(1/2-2)$ [see e.g., Ref. [13]]. Thereby, the see-saw formula [14] yields: $m(\nu^\tau_L) \approx [(120GeV)^2/(4 \times 10^{14}GeV)](1/2-2) \approx (1/30eV)(1/2-2)$, in good agreement with the SuperK data! Note, while the Dirac mass of the tau neutrino gets determined within symmetries containing $SU(4)$-color, as in $G(224)$ or $SO(10)$, it would be completely arbitrary within symmetries like $SU(5)$ [5], $[SU(3)]^3$ and flipped $SU(5)$. In this sense, the mass of the ν_τ, suggested by the SuperK data, seems to select out the route to higher unification based on SUSY $SO(10)$ or a string-derived $G(224)$, as opposed to the alternative routes.

(v) Some intriguing features of fermion masses and mixings: Confining to a minimal choice for the Higgs system, successful frameworks for describing fermion masses and mixings, based on $SO(10)$ or $G(224)$-symmetry, have been recently proposed (see in particular Ref.[15] and [16]). They yield some eight (or nine) predictions including: $m_b(m_X) \approx m_\tau(M_X)$; $m(\nu^\tau_L) \approx 1/30eV(1/2-2)$ (mentioned above); large or maximal $\nu_\mu - \nu_\tau$ oscillation angle together with small $V_{cb} \approx 0.043$; $\theta_{Cabibbo} \approx 0.22$; $m_d \approx 8MeV$ and $V_{ub} \approx 0.003$, all of which agree with observation to within 10%.

(vi) Baryogenesis : To implement baryogenesis [17] successfully, in the presence of electroweak sphaleron effects [18], which wipe out any baryon excess generated at high temperatures in the $(B\text{-}L)$-conserving mode, it has become apparent that one would need $B\text{-}L$ as a generator of the underlying symmetry, whose spontaneous violation at high temperatures would yield, for example, lepton asymmetry (leptogenesis). The latter in turn is converted to baryon-excess at lower temperatures by electroweak sphalerons. This mechanism, it turns out, yields even quantitatively the right magnitude for baryon excess [19]. Now $B\text{-}L$ is a generator of SU(4)-color, which is contained in G(224) or SO(10), but not in SU(5).

All these pieces (i)-(vi) fit beautifully together within a single puzzle board framed by supersymmetric unification, based on $SO(10)$ or a string-unified $G(224)$ symmetry. *The one and the most notable piece of the puzzle still missing, however, is proton decay.*

Theoretical analysis of proton decay has been recently carried out by two groups of authors [15, 20, 21], within the minimal supersymmetric $SO(10)/G(224)$ – framework, by paying special attention to its dependence on the masses and mixings of all fermions, including neutrions and on the unification-scale threshold effects. Allowing for generous but plausible uncertainties in the relevant parameters – i.e. the SUSY spectrum (in accord with the argument of fine tuning [22]), hadronic matrix element (in accord with recently improved lattice result [23]), and $\tan\beta$ (in agreement with Higgs mass-limit that sets $\tan\beta \geq 3$ [24]) – and also allowing for certain well-motivated variants of MSSM [25], these analyses lead to the conclusion that *a conservative upper limit* on proton lifetime for the case of SUSY $SO(10)$ or $G(224)$ is given by $(1/2 - 2) \times 10^{34}$ yrs, with $\bar{\nu}K^+$ being the dominant mode, and μ^+K^0 and possibly $e^+\pi^0$ being prominent. [For comparison it may be noted that the corresponding upper limit for the case of minimal SUSY $SU(5)$ is about $(0.5) \times 10^{33}$ yrs, which is however excluded by the present empirical lower limit of 1.6×10^{33} yrs, set by SuperK].

Thus unless the fitting of all pieces listed above is a mere coincidence (and it is hard to believe that that is the case), an improvement in the current sensitivity by a factor of five to ten (compared to SuperK) ought to produce real events of proton decay. Otherwise, some promising and remarkably successful ideas on unification would suffer a major setback.

3 Conclusion

To conclude, the discovery of proton decay would undoubtedly constitute a landmark in the history of physics. It would provide the last, missing piece of gauge unification and would shed light on how such a unification may be extended to include gravity in the context of a deeper theory.

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Basic Constituents of the Visible and Invisible Matter — A Microscopic View of the Universe

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Samanta Chandra Sekhar has a unique place in modern Indian history as the last leading light of our ancient scientific heritage. He combined remarkably accurate astronomical observations by the most primitive tools with very intricate mathematical analysis using our ancient sutras; and arrived at results of comparable accuracy to what was then the state of the art. It is little wonder therefore that his treatise, Siddhānta Darpana, had hit the headlines of "The Nature" and "Knowledge" back in 1899 and he remains a household legend in Orissa to this date. However it is a sad commentary on our national science organisations that his name is practically unknown outside his home state. It is therefore very heartening to see the efforts made by the Samanta Chandra Sekhar Amateur Astronomers' Association to fill this glaring gap. Let me present this article as a small token of my appreciation for their endeavour.

1 Introduction

Our concept of the basic constituents of matter has undergone two revolutionary changes during the twentieth century. The first was the Rutherford scattering experiment of 1911, bombarding Alpha particles on the Gold atom. While most of them passed through straight, occasionally a few were deflected at very large angles. This was like shooting bullets at a hay stack and finding that occasionally one would be deflected at a large angle and hit a bystander or in Rutherford's own words "deflected back and hit you on the head"! This would mean that there is a hard compact object hiding in the hay stack. Likewise the Rutherford scattering experiment showed the atom to consist of a hard compact nucleus, surrounded by a cloud of electrons. The nucleus was found later to be made up of protons and neutrons.

The second was the electron-proton scattering experiment of 1968 at the Stanford Linear Accelerator Centre, which was awarded the Nobel Prize in 1990. This was essentially a repeat of the Rutherford scattering type experiment, but at a much higher energy. The result was also similar as illustrated below. It was again clear from the pattern of large angle scattering that the proton is itself made up of three compact objects called quarks.

We now know from many such experiments that the nuclear particles (proton, neutron and mesons) are all made up of quarks – i.e. they are all quark atoms.

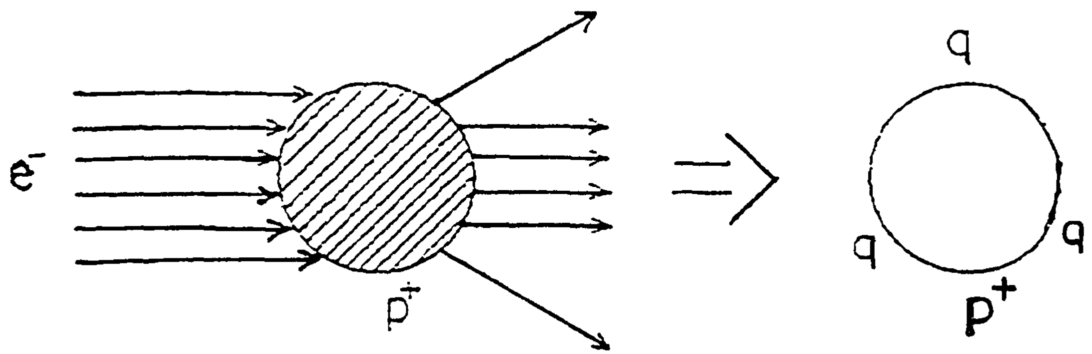


Fig. 1. The SLAC electron-proton scattering experiment, revealing the quark structure of the proton.

The main difference between the two experiments comes from the fact that, while the dimension of the atom is typically $1A^\circ = 10^{-10}$ m that of the proton is about 1 fm (fermi or femtometer) $= 10^{-15}$ m. It follows from the famous Uncertainty Principle of Quantum Mechanics,

$$\Delta E \cdot \Delta x > \hbar c \sim 0.2 \text{ GeV.fm}, \tag{1}$$

that the smaller the distance you want to probe the higher must be the beam energy. Thus probing inside the proton ($x \ll 1$ fm) requires a beam energy $E \gg 1$ GeV(10^9 eV), which is the energy acquired by the electron on passing through a billion (Gega) volts. It is this multi-GeV acceleration technology that accounts for the half a century gap between the two experiments.

It is customary in quantum physics to use the so called natural units, where one sets both the Plank's constant $\hbar$ and the velocity of light c equal to unity. Thus the mass of particle is same as its rest mass energy (mc^2). The GeV is commonly used as the basic unit of mass, energy and momentum. The proton mass is nearly 1 GeV.

2 The Standard Model

As per our present understanding the basic constituents of matter are a dozen of spin-1/2 particles (in units of $\hbar$) called fermions, along with their antiparticles. These are the three pairs of leptons (electron, muon, tau and their associated neutrinos) and three pairs of quarks (up, down, strange, charm, bottom and top) as shown below. The masses of the heaviest members are shown paranthetically in GeV units.

Basic Constituents of Matter

leptons	ν_e	ν_μ	ν_τ	0
	e	μ	$\tau(2)$	-1
quark	u	c	$t(175)$	2/3
	d	s	$b(5)$	$-1/3$

The members of each pair differ by 1 unit of electric charge as shown in the last column – i.e. charge 0 and -1 for the neutrinos and charged leptons and 2/3 and -1/3 for the upper and lower quarks. This is relevant for their weak interaction. Apart from this electric charge the quarks also possess a new kind of charge called colour charge. This is relevant for their strong interaction, which binds them together inside the nuclear particles.

There are four basic interactions among these particles – strong, electromagnetic, weak and gravitational. Apart from gravitation, which is too weak to have any perceptible effect, the other three are all gauge interactions. They are all mediated by spin 1 (vector) particles called gauge bosons, whose interactions are completely specified by the corresponding gauge groups.

Basic Interactions

Interaction	Strong	EM	Weak
Carrier	g	γ	$W^\pm \& Z^0$
Gauge Group	$SU(3)$	$\underbrace{U(1)\quad SU(2)}$	

The strong interaction between quarks is mediated by the exchange of a massless vector boson called gluon. This is analogous to the photon, which mediates the electromagnetic interaction between charged particles (quarks or charged leptons). The gluon coupling is proportional to the colour charge just like the photon coupling is proportional to the electric charge. The constant of proportionality for the strong interaction is denoted by α_s in analogy with the fine structure constant α in the EM case, as shown in equations (2) and (3) below. And the theory of strong interaction is called quantum chromodynamics (QCD) in analogy with the quantum electrodynamics (QED). The major difference of QCD with respect to the QED arises from the nonabelian nature of its gauge group, $SU(3)$. This essentially means that unlike

the electric charge the colour charge can take three possible directions in an abstract space. These are rather whimsically labelled red, blue and yelow as illustrated below. Of course the cancellation of the colour charges of quarks ensure that the nuclear particles composed of them are colour neutral just like the atoms are electrically neutral.

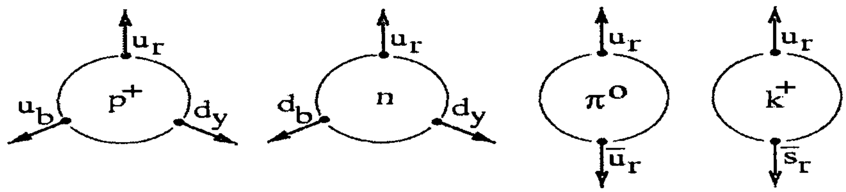


Fig. 2. The quark structure of proton, neutron, π and K mesons along with their colour charges (the bar denotes antiparticles and the subscripts denote colour charge).

A dramatic consequence of the nonabelian nature of the QCD is that the gluons themselves carry colour charge and hence have self-interaction unlike the photons, which have no electric charge and hence no self-interaction. Because of the gluon self-interaction the colour lines of forces between the quarks are squeezed into a tube as illustrated below.

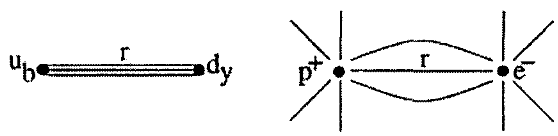


Fig. 3. The squeezed (1-dimentional) lines of force between colour charges contrasted with the isotropic (3-dimentional) lines of force between electric charges.

Consequently the number of colour lines of force intercepted and the resulting force is constant, i.e. the potential increases linearly with distance

$$V_S = \alpha_s r. \tag{2}$$

Thus the quarks are perpetually confined inside the nuclear particles as it would cost an infinite ammount of energy to split them apart. In contrast the isotropic distribution of the electric lines of force implies that the number intercepted and hence the resulting force decreases like $1/r^2$, i.e. the potential

$$V_E = \frac{\alpha}{r}. \tag{3}$$

Finally the weak interaction is mediated by massive vector particles, the charged $W^{\pm}$ and the neutral Z^0 bosons, which couple to all the quarks and leptons. The former couples to each pair of quarks and leptons listed above with a universal coupling strength α_W, since they all belong to the doublet representation of $SU(2)$ (i.e. carry the same gauge charge). Because of the mass of the exchanged particle M_W the weak interaction is restricted to a short range of $1/M_W$, i.e.

$$V_W = \frac{\alpha_W}{r} e^{-rM_W}. \tag{4}$$

One can understand this easily from the uncertainty principle (1), since the exchange of a massive W boson implies a tansient energy nonconservation $\Delta E = M_W c^2$, corresponding to a range $\Delta x = \hbar / M_W c$.

The weak and the electromagnetic interactions have been successfully unified into a $SU(2) \times U(1)$ gauge theory. This is the famous electroweak theory of Glashow, Salam and Weinberg for which they were awarded the 1979 Nobel Prize. This theory predicts the W and Z boson masses from the relative rates of the weak and the electromagnetic interactions, i.e.

$$M_W = 80 \text{ GeV and } M_Z = 91 \text{ GeV}. \tag{5}$$

3 Discovery of the Fundamental Particles

As mentioned earlier, the up and down quarks are the constituents of proton and neutron. Together with the electron they constitute all the visible matter of the universe. The heavier quarks and charged leptons all decay into the lighter ones via weak interaction analogous to the nuclear Beta decay. So they are not freely occurring in nature. But they can be produced in laboratory or cosmic ray experiments. The muon and the strange quark were discovered in cosmic ray experiments in the late forties, the latter in the form of K meson. Next to come were the neutrinos. Although practically massless and stable the neutrinos are hard to detect because they interact only weakly with matter. The ν_e was discovered in atomic reactor experiment in 1956, for which Reines got the Nobel Prize in 1995. The ν_μ was discovered in the Brookhaven proton synchrotron in 1962, for which Lederman and Steinberger got the Nobel Prize in 1988. The first cosmic ray observation of neutrino came in 1965, when the ν_μ was detected in the Kolar Gold Field experiment.

The rest of the particles have all been discovered during the last 25 years, thanks to the advent of the electron-positron and the antiproton-proton colliders. First came the windfall of the seventies with a quick succession of discoveries mainly at the e^+e^- colliders: charm quark (1974), Tau lepton (1975), bottom quark (1977) and the gluon (1979). This was followed by the discovery of W and Z bosons (1983) and finally the top quark (1995) at the $\bar{p}p$ colliders. Richter and Ting got the Nobel prize for the discovery of charm quark, while Martin Pearl got it for the Tau Lepton and Carlo Rubbia for the W and Z bosons.

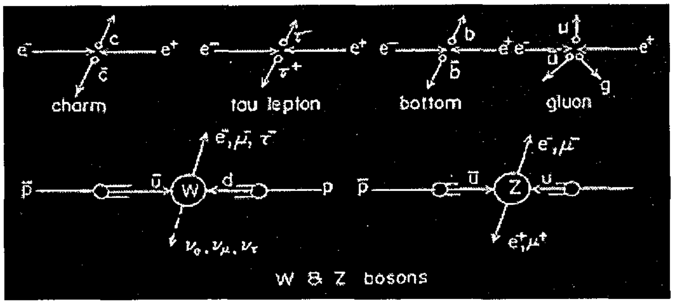


Fig. 4. Production of charm quark, tau lepton, bottom quark and gluon at the e^+e^- collider (upper line) and W and Z bosons at the $\bar{p}p$ collider (lower line).

Fig. 4 illustrates the pair production of charm and bottom quarks as well as the tau lepton at the electron-positron collider. The typical lifetime of these particles is of the order of a picosecond (10^{-12} sec.), corresponding to a range of a few hundred microns (fraction of a milli meter) at relativistic energies. Thanks to the high resolution silicon detectors available now, one can identify these particles before they decay. On the other hand the W and Z bosons, being very heavy, decay practically at the instant of their creation. Nontheless they can be recognised by the unmistakable imprints they leave behind in their decay products. The same is true about top quark production (not shown).

Thus we have seen all the basic constituents of matter and the carriers of their interactions by now. But the story is not yet complete because of the mass problem – i.e. how to give mass to the weak gauge bosons (and also matter fermions) without breaking the gauge symmetry of the Lagrangian.

4 Mass Problem (Higgs Boson)

It is a remarkable property of gauge theory that the interaction dynamics is completely determined by the symmetry of the Lagrangian under the gauge transformation – i.e. rotation in some abstract space defined by the gauge group. This is similar to the rotational symmetry of the Lagrangian in ordinary space, leading to the conservation of angular momentum, except that in this case you assume the rotation angles to vary from point to point (i.e. be localised). Then it predicts not only the conservation of gauge charges but also the presence of massless vector particles (gauge bosons) along with their couplings to the matter fermions. But the mass term of the gauge bosons (as well as those of the matter fermions) can be easily seen to break the gauge symmetry of the Lagrangian. On the other hand the scalar (spin-0) particle masses are symmetric under gauge transformation. This can be exploited to give mass to the weak gauge bosons as well as the matter fermions through the back door – i.e. they acquire mass by absorbing scalar particles (like a snake acquiring mass by swallowing a frog).

This is the famous Higgs mechanism. One assumes a scalar particle of negative mass square, i.e. imaginary mass. This leads to a spontaneous symmetry breaking – i.e. the ground state of energy is not symmetric under gauge transformation unlike the Lagrangian. As a result the gauge bosons, W and Z, can acquire mass. Besides the physical scalar particle acquires a real mass, comparable to W and Z masses. This is the so called Higgs boson, whose detection will confirm this mechanism of generating particle masses. It may be noted here that one can have a consistent gauge theory of electroweak interaction in the presence of spontaneous symmetry breaking, since the Lagrangian retains the gauge symmetry. This was demonstrated by t'Hooft and Veltman in the early seventies, for which they got the Nobel prize last year.

There are many examples of spontaneous symmetry breaking in physics, the most familiar one being that of magnetism. At high temperature the electron spins of a Ferromagnet are randomly oriented. But as we cool it below a critical temperature the electron spins get alligned with one another because that corresponds to a lower state of energy (ground state). Thus while the Lagrangian posseses a rotational symmetry, this is not shared by the ground state. The same thing happens in the Higgs mechanism, except that the rotation is to be done in an abstract space instead of the ordinary space.

5 The Standard Model of Cosmology

A phase transition similar to the Ferromagnetic one had taken place soon after the big bang, when the universe was only a few picoseconds (10^{-12} sec.) old. It was an extremely hot and dense fire ball, with an ambient temperature of about 100 GeV. Now the effective mass of a particle depends on the property of the medium. And as the universe cooled down below a critical temperature the effective squared mass of the scalar particle became negative, resulting in a spontaneous breaking of the electroweak symmetry. At this stage the W and Z bosons acquired mass along with the quarks and the leptons. The age of the universe varied inversely as the square of its temperature. By the time the universe was about a microsecond (10^{-6} sec.) old, the ambient temperature had dropped to about 1 GeV and all the W and Z bosons had decayed along with the heavy quarks and leptons into the light ones. At this stage a second (QCD) phase transition took place, which confined the light quarks (u and d) into protons and neutrons. It may be noted here that the ongoing heavy ion collision experiments are trying to recreate such a QCD phase transition in the laboratory; and there are already some early indications of success.

By the time the universe was a few minutes (10^2 sec.) old the temperature had dropped to a few MeV, which is the typical binding energy of nuclei. At this stage Helium and other light nuclei were formed. After about one lakh (10^5) years the temperature dropped down to the atomic binding energy level of a few electron volts. At this stage the electrons combined with the nuclei to form neutral atoms. Thus the matter decoupled from radiation and the universe became transparent. After this the matter particles experienced the gravitational attraction resulting finally in the

formation of galaxies and stars. The present age of the universe is about 15 billion years and the ambient temperature about 3 K (1 eV = 12000 K).

6 Hierarchy Problem (Supersymmetry)

But this is not the end of the story because of the so called hierarchy problem – i.e. how to control the Higgs boson mass in the mass range of W and Z bosons (around a hundred GeV)? This is because the scalar particle mass has a quadratically divergent quantum correction unlike the fermion and gauge boson masses, since it is not protected by any symmetry. Thanks to the uncertainty principle, the vacuum in quantum mechanics is not empty, but it can contain an unlimited amount of energy and matter. And the quantum correction represents the effect of this medium on the mass of a particle. Being a divergent effect it would push up the scalar particle mass to infinity (or a very high cutoff scale of the theory). So the question is how to keep it down in the desired mass range of W and Z bosons?

That the scalar mass is not protected by any symmetry was of course used above to give mass to gauge bosons and fermions via Higgs mechanism. The hierarchy problem encountered now is the flip side of the same coin. The most attractive solution is to invoke a protecting symmetry – i.e. the supersymmetry (SUSY), which is a symmetry between fermions and bosons. As per SUSY all the fermions of the Standard Models have bosonic Superpartners and vice versa. They are listed below along with their spins S, where the Superpartners are indicated by tilde. The presence of the Superpartners ensure cancellation of the divergent quantum corrections.

quarks & leptons	S	Gauge bosons	S	Higgs	S	R-parity
q, ℓ	1/2	γ, g, W, Z	1	h	0	+1
$\tilde{q}, \tilde{\ell}$	0	$\tilde{\gamma}, \tilde{g}, \tilde{W}, \tilde{Z}$	1/2	$\tilde{h}$	1/2	-1

The standard particles are distinguished from the supersymmetric ones by a multiplicative quantum number called R-parity, which is $+1$ for the former and -1 for the latter. Thus the supersymmetric particles have to be produced in pair and the lightest supersymmetric particle (LSP) has to be stable for R-parity conservation. In most SUSY models the LSP is the photino $\tilde{\gamma}$, or in general mixture of $\tilde{\gamma}$ and $\tilde{Z}$, with a mass of again about a hundred GeV. Thus it interacts only weakly with matter and hence hard to detect like the neutrino. Indeed the LSP is the leading candidate for constituting the invisible or dark matter of the universe, which will be the last topic of this article.

7 The Invisible (Dark) Matter

There is a large number of indirect evidences suggesting that the bulk of the matter of the universe is invisible or dark – i.e. it has gravitational but no electromagnetic

interaction! The strongest evidence comes from the rotational velocity of the isolated stars or hydrogen cloud on the outskirts of galaxies. One can predict this velocity by balancing the centrifugal acceleration with the gravitational one,

$$\frac{v_{rot}^2}{r} = \frac{G_N M(r)}{r^2}, \text{ i.e. } v_{rot} = \sqrt{\frac{G_N M(r)}{r}}, \tag{6}$$

where r is the distance of the tracer star from the galactic centre and $M(r)$ is the galactic mass enclosed within this distance. Fig. 5 shows the rotation curve for a nearby dwarf spiral galaxy M33, superimposed on the optical image. If there were no galactic matter outside the visible disk the rotation velocity curve would have gone down like $1/\sqrt{r}$. Instead it continues to rise towards a constant value, way beyond the visible disk, suggesting that there is a lot of invisible matter in and around the galaxy. Similar rotation curves have been observed for about a thousand galaxies, including our own. And they suggest the mass of the invisible matter to be a over an order of magnitude larger than the mass of visible matter.

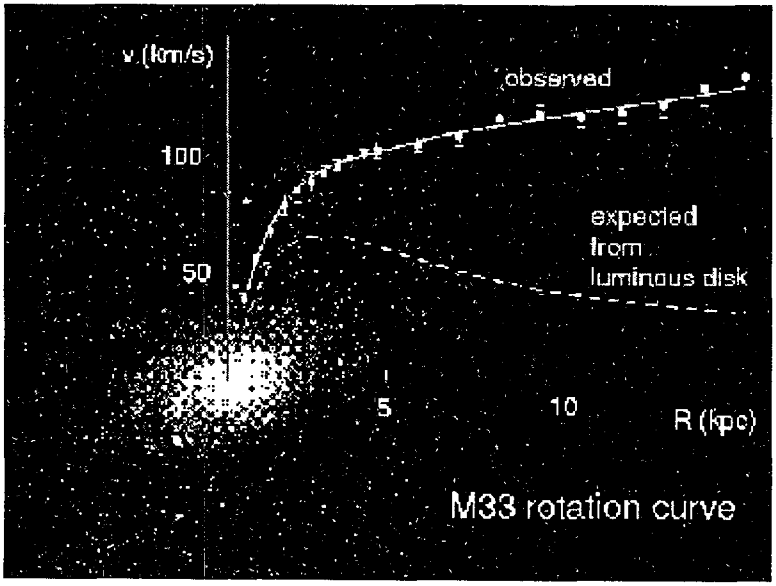


Fig. 5. observed rotation curve of the nearby dwarf spiral galaxy M33, superimposed on its optical image (adopted from E. Corbelli and P. Salucci, astro-ph/9909252, 1999).

The invisible mass could of course come from nonluminous bodies like small stars or Jupitor, which are more aptly described as dark rather than invisible matter. But such objects act as gravitational lense, which distort the image of distant stars lying behind them by gravitational bending of light. And it is clear from these gravitational lensing experiments that such massive compact objects can not be a major source of

the invisible matter. The contribution from gas is also very small. In principle the neutrinos could constitute the invisible matter; but their masses are too small to account for the required density of invisible matter. The leading candidate for this is the lightest supersymmetric particles (LSP), which are weakly interacting like the neutrino but carry a mass of about a hundred GeV. These particles were in thermal equillibrium with W, Z and Higgs bosons along with the quarks and leptons when the universe had a temperature of about a hundred GeV. But as the temperature dropped by about an order of magnitude, the density of LSP came down to a level, where their annihilation rate could not keep up with the expansion rate of the universe. The latter took them away from one another before they could mutually annihilate. Thus the total mass of the LSPs at this (freeze out) temperature has remained the same ever since. Indeed this scenario predicts the right size of the invisible matter density we observe today.

Presumably these invisible particles played a pioneering role in galaxy formation. Being neutral particles they would have experienced gravitational attraction long before the formation of neutral atoms, when the ordinary matter started experiencing this attraction. Thus it is quite plausible that the local concentrations of invisible matter had already formed by the time of formation of the neutral atoms, to which the latter were gravitationally attracted to form the galaxies. Indeed such a scenario of structure formation is supported by strong observational evidence.

Thus the invisible matter is a very important component of the universe. There are multiprong experimental efforts for detection of these invisible particles. Extremely high precission detectors are being set up in deep underground experiments to record their interaction with ordinary matter by measuring the recoil energy of the target nuclei. A square kilometer size neutrino telescope is being setup in the polar ice cap of Antartica to look for the high energy neutrinos coming from the pair annihilation of these invisible particles, a large concentration of which is gravitationally trapped at the solar core. Most importantly a large proton-proton collider of 27 km circumfurence is being built by an international collaboration near Geneva to produce these particles in the laboratory by recreating the extremely high temperature and energy density, that existed after a nanosecond of the big bang. Assuming these invisible particles to be the LSP one can be reasonably confident of producing them at this collider along with the Higgs boson. Thus one hopes to finally solve the mystry of the invisible matter of the universe as well as to understand how the visible matter acquires mass.



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Dark Matter and a Parallel Universe

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1 Introduction

It must have been an insatiable curiosity to learn about the universe around him that drove Samanta Chandrasekhar to spend his entire life looking at the planets and stars without a sophisticated telescope or camera, night after night and record all his finding meticulously for the generations to come !! Fortunately, the same curiosity lives on and is what drives the astronomers, astrophysicists and cosmologists of today to devote their entire scientific careers and brilliant minds to study a subject, they cannot touch and barely see but can mostly imagine through the interpretation of pictures on a computer screen. The exploration into the nature and evolution of the universe that began as early as the days of ancient Greeks and acquired milestone after milestone through the ages, through incessant human toil and sacrifice, is finally reaching a level of maturity that is incredibly impressive as we start the new millenium. It is therefore a most appropriate time to pay homage to a local astrnomer genius who slowly but methodically added brick after brick to a rising cathedral of knowledge, that is only now beginning to acquire its true form.

The story that I will describe here concerns but one facet of this rich area of investigation and about which today there are probably more questions than answers. The subject is, the nature of the most abundant form of matter in the universe, the dark matter.

Dark matter, as the name implies, is a form of matter, that neither emits or absorbs light. It is supposed to pervade the entire universe. When we look up at the sky on an October night, we see millions of stars that fill the night sky with their twinkle. We see the stars in our own galaxy, the Milky way galaxy- there are about 100 billion of them; we see them from galaxies outside our own, which each have hundred billion of their's each etc. These stars are made of familiar matter: i.e. proton, neutron and electron, that make up all animals, plants, rocks and any thing else that wee around us every day. These are not what the universe dominantly made out of.

Extensive observations by astronomers have made it possible to estimate the total amount of matter in the universe contained in this visible, the twinkling stars and their siblings, the red giants, white dwarfs, neutron stars, planets etc. Many observations however have given indications for more than 70 years that the story of matter in the in the universe is a much more complex one. There is more to matter than "meets the eye". A larger part of the mass of the universe is in a form hidden to the "eye". This is called the dark matter.

The existence of dark matter was first suspected by astronomer F. Zwicky in 1933 from the observations of Doppler shift of spectral lines of galaxies in the Coma cluster. Doppler shift is the phenomenon that we experience when we hear the changing pitch of the whistle sound of a passing train standing near a track. The faster they recede from us, the slower the pitch of sound becomes. The same phenomenon for light waves is used to measure the velocity of distant stars and galaxies as they move about in the gravitational field of matter in their surroundings. As they move away from us, their emitted light looks more and more red- the "pitch" of light becomes less. This is called red shift. Studying the red shift of light from galaxies in the Coma cluster, Zwicky derived their velocities. Since those velocities could have only been the result of the gravitational pull of matter around, he could estimate the amount of matter in the cluster. To his surprise, he found that his estimate of the total matter around far exceeded what was known to have been in the stars and galaxies that were observed. From this he concluded that there must be invisible matter in the cluster that is pulling the galaxies at a faster rate than expected on the basis of visible matter. The subject of dark matter physics was born on that day. Years of investigation since then have now established beyond a doubt that indeed the most abundant form of matter is not the matter that we see in the form of galaxies, stars and planets but invisible matter, whose nature we do not know. There are now more than two dozen experiments which in some form or another are trying to decipher the nature of this dark matter.

Let us first discuss briefly the different observations that confirmed Zwicky's suspicion. Two primary sources from where the evidence for dark matter has come are: (i) the observation of the so called rotation curves in thousands of galaxies and (ii) the velocities of galaxies in clusters, such as the one that led Zwicky in the first place to suspect the existence of dark matter and (iii) more recently from the study of angular pattern of the left over radiation from the early moments of the big bang that created the universe.

Galactic rotation curves

Rotation curves measure the velocities of hydrogen atoms in the far out regions of galaxies and thereby measure the total amount of mass. It is found that there is more mass than that contained in stars. These measurements have been done in thousands of galaxies such as the spiral galaxies like our own Milky way galaxy, Dwarf galaxies, low surface brightness galaxies etc. Typically, it is found that the dark matter extends to a distance of about 20 to 30 kilo parsecs (which is about 10 times the distance to which visible matter extends). These studies have also revealed the density profile of the dark matter, which has in recent days been an object under great deal of scrutiny since they may be telling us about the detailed nature of the dark constituent that makes up the dark matter.

Clusters of Galaxies

Clusters of galaxies are the largest gravitationally bound systems and give evidence for dark matter on the distance scales of megaparsecs that far exceeds the galactic scales. The general principle here is again same as in the previous case i.e. velocities of galaxies are a measure of the surrounding mass. The advent of x-ray telescopes in the mid-1960's enabled much more reliable studies of these systems and only served to confirm the existing evidence. It is now believed on the basis of these studies that dark matter constitutes about 30 per cent of the mass of the universe whereas the visible mass contribute about five per cent or so.

Cosmic microwave background radiation

Finally there is evidence from recent studies of the fine structure in the cosmic microwave back ground that the total mass energy content of the universe is nearly equal to the critical density. (Critical density $\rho_c = \frac{3H_0^2}{8\pi g_N}$, where H_0 is present value of the Hubble expansion parameter, i.e. the ratio of the velocity to distance to distant objects in the universe and G_N is the Newton's constant. The universe closes and recontracts if measured ρ is bigger than ρ_c and keeps expanding for ever in the opposite case.) Since , as was mentioned above, the visible matter content of the universe is of the order of 5% or so, this implies that there is some hidden form of energy. In fact there is independent information from studies of type I supernovae that of the remaining 95%, perhaps as much as 60% is in the form of a hidden energy, the cosmological constant. This leaves about 30% to be accounted for as dark matter.

This is not however the end of the trail of evidences. There are several more coming from the so-called lensing experiments. To understand the lensing phenomenon, recall the ordinary eye glasses, which improve your vision. They do this by bending light as it passes through the lens made out of glass or plastic. Exactly same thing can happen to light as it passes near a huge chunk of matter. According to Einstein's theory of general relativity, gravitational effect of matter is equivalent to bending of space. The effect of matter on the path of light can therefore be described by assuming that there is no matter but the lines along which light *can* travel are curved. Thus gravity can bend light the same way that eye glasses bend it. Of course the gravity bending is a much weaker phenomenon than the bending by eye glasses- so we do not see it every day. The effect can however be quite pronounced when there are large chunks of matter such as a galaxy or even a big star. The lensing effect therefore provides a new way to search for the existence of dark matter. The interesting point is that such effects have been seen in two classes of experiments: one where galaxy lensing has given evidence for dark matter on galactic scales; a second one called micro-lensing where lensing effects have been seen by dark stars with mass about half the solar mass in our own Milky way galaxy in the line of sight towards the Large Magellanic Cloud, which consists of millions of stars. The second class of experiments were carried out by a collaboration called MACHO and the seventeen or so dark objects whose

lensing effect was observed are also called MACHOs (acronym for massive compact halo objects).

2 What is the dark matter made of?

An immediate question raised by the evidence for dark matter is: what is the nature of the particle that dark matter is made of. It cannot be the familiar particles such as the proton, neutron or the elctron since they all "glow" in the dark. Years of research in particle physics has revealed that proton, neutron and electron are not the only "fundamental"particles in the universe; but there are others knwon as the charm, strange and muon, an identical but heavier species than the up, down (that make up the proton and the neutron) and the electron followed by top, bottom and the tau-lepton. These are the particles that make up the back bone of the standard model and they interact via the exchange of "force" particles called the W, Z photon and the gluon. This is known as the standard model and the natural question is : could any of these heavier particles of the standard model be the dark matter constituent ? The answer is unfortunately "no" for the very simple reason that they are all very shortlived and disappear from the universe, when it is very young.

This question of dark matter is therefore a perplexing as well as an interesting one at this moment in the history of physics, since as described,the standard model is experimentally confirmed theory of all matter and forces and has no need for anything that could qualify as the dark matter particle. There is no known piece of experimental data that indicates any deviation from this theory, except for the mass of the neutrinos. Repeated attempts to find deviations have only ended up in confirming their absence. This has created a very frustrating situation. Thus, evidence for dark matter raises an exciting possibility that aside from the neutrino mass, it is one of the first clues to the physics beyond the standard model. Understanding the nature of the dark matter, therefore, is going to open up the next frontier in our search for the final theory of everything. The first physics revolution of the 21st century may not be too far in the future.

There are many new physics scenarios which provide candidates for dark matter particle. Essential criterion for such a particle is that it must be absolutely stable (or at least longer lived than the universe); its abundance in the universe must be just right to lead to its present concentration at 30% mass for the universe. The latter, generally termed relic dark matter density, depends on the annihilation cross section of the particles with their anti-particles. If the annihilation is too efficient, very few of these particles will survive the process and their contribution to dark matter content of the universe will be insufficient; on the other hand if the annihilation process is too sluggish, too many will be left over and the universe will overclose. A fine balance is required for most species of dark matter.

If an independently motivated new physics scenario leads to a candidate that staisfies these two minimal criteria, then it has to be taken seriously in dark matter studies. As it turns out there are a large number of scenarios with such candidates.

Two of the most popular ones are the lightest particle of a supersymmetric theory, whose mass is expected to be around 50 to 200 GeV and whose annihilation cross section can be adjusted to fit the known dark matter density and an ultralight particle known as the axion.

Supersymmetric dark matter

There are two fundamentally different kinds of matter in nature, the bosons and fermions, bosons having integral spin were named after Indian physicist S. N. Bose and fermions, with half integral spin were named after Italian physicist, Enrico Fermi. In nature, the fermions seem to correspond the building blocks of matter whereas the bosons play the role of carriers of forces. For a long time it was thought that any search for complete unification of matter and forces will remain incomplete since bosons and fermions being so different can never be unified. However, it was realized in the early 70's by Russian physicists Golfand, Likhtman, Akhulov and Volkov and European physicists Wess and Zumino, one can write theories which have the grand symmetry between bosons and fermions, known as supersymmetry. According to this theory, each particle of half integral spin (or a fermion) must be accompanied by an integral spin particle (or a boson) and vice versa. The fermion-boson symmetry leads to an immediate mathematical advantage that it makes the quantum field theory of supersymmetric models much more manageable than the nonsupersymmetric ones. In turn, this feature has led to a wide spread belief that supersymmetry can solve several very difficult conceptual problems with the standard electroweak model of particle physics and put it on a more sound basis. This connection to standard model is possible only if the superpartners of the familiar particles have masses in the hundred GeV range, a range that can be be explored with the present day accelerators. For all these reasons, supersymmetry has been the subject of intense activity during the past two decades both on theoretical and experimental front.

An important consequence of the particle doubling feature of supersymmetric theories is that the superpartners of known particles can only be produced in pairs in a collision of two familiar particles, as in typical colliders and whenever a superpartner decays, it has to involve a superpartner as one of the decay products. This immediately implies that the lightest of the superpartners (LSP) of known particles has to be stable. This particle will therefore remain as a relic of the big bang and can play the role of dark matter, if its abundance is appropriate. It turns out that what is experimentally known about supersymmetry allows abundances of the LSP to be enough for it to play the role of dark matter. LSP is therefore one of the prime candidates for dark matter of the universe and is being searched for in many underground experiments around the world.

Axion

The particle axion was proposed by American physicists R. Peccei and H. Quinn in the late 70's to solve an important puzzle of the standard model in the domain

of nuclear physics, i.e. an excessive amount of matter-anti-matter asymmetry in contradiction with experiment. The presence of the axion particle solves this problem in a very novel manner. The axion is an ultralight particle and therefore care must be taken to ensure that its production in the core of the stars does not upset our successful understanding of the Sun and other stars. There is however no argument forbidding its presence as a dark matter of the universe. Thus both theories of dark matter are extremely well motivated by problems of the standard model.

There are many underground experiments looking for the supersymmetric dark matter at various places around the world: USA, Italy and England to name a few; more are in the planning stage and will go into operation in the next few years. There are already results from many of these experiments. Except for the Italian experiment known as DAMA, all other experiments give negative results. The Americal CMS experiment is in disagreement with the DAMA experiment.

Similarly for the axion, there have been extensive searches using a method proposed by theorist, P. Sikivie, where a microwave cavity photon is used to excite the supposed axion in the galaxy to emit another photon, a possibility predicted by the axion theory. So far the search has not yielded any sign of the axion.

In this article, I will describe a third kind of dark matter particle that is suggested by the celebrated string theories and indicated by several results in the domain of neutrino physics. This form of dark matter, to be called mirror matter has the interesting property that in its true form it suggests the existence of a parallel universe similar to ours in both its matter and force content but with the difference that matter in this parallel (mirror) sector is about ten to 30 times heavier. In its physics content, therefore, this form of dark matter and the associated parallel universe is very easy to understand: it is same as we are but a little heavier.

It turns out that this slight heaviness endows the parallel universe with several interesting features, one of which is that it explains the observed dark matter content. In this article, I will explain this and other intriguing features of this model and argue that we may be seeing tell-tale signs of mirror matter (e.g. mirror stars) in several experiments, that are currently probing the skies for unravelling the properties of dark matter.

3 Possible problems with axion and supersymmetric dark matter

It is possible to argue that the mirror dark matter has certain conceptual as well as perhaps practical advantages over the other two candidates, the supersymmetric particle and the axion, just mentioned. Hints of this has come from more detailed studies of the galactic halos, which are supposed to be dominated by dark matter as well from other related considerations.

To see them, let us note that, studies of detailed dark matter properties have led to several puzzles, both conceptual as well as observational. They are: (i) why is it that the contribution of baryons to the mass density (Ω) of the universe is almost of the same order as the contribution of the dark matter to it ? (ii) how does one understand

the dark objects with mass $\sim 0.5 M_\odot$ observed in the MACHO experiment, which are supposed to constitute up to 20% of the mass of the halo of the Milky way galaxy and are presumably connected to the dark constituent that contributes to Ω ? and, finally (iii) what explains the density profile of dark matter in galactic halos; in particular, the evidence that the core densities of galactic halos of dwarf as well as low surface brightness galaxies remain constant as the radius goes to zero ? Apart from the simple requirement that the right dark matter candidate must have properties that allow it to have the requisite relic density and mass to dominate the mass content of the universe, it should be required to provide a satisfactory resolution of three puzzles of dark matter physics noted above. It appears that, in contrast with the supersymmetric particle and the axion, the mirror dark matter has the right properties to solve these puzzles. In this article, I will try to explain these properties in a qualitative manner.

To see what problems are encountered by the popular supersymmetric dark matter as well as axion in explaining the halo density behavious, first point to note is that these particles have no self interactions. In other words if a gas of these particles are left to themselves at a very low temperature, they will eventually settle to the center of attraction due to the effects of gravity. Therefore, the mass density profile of such a conglomerate will have peaking effect towards the center. It turns out that these qualitative considerations are fully reproduced by sophisticated computer models of the dark matter halos made out of non-interacting dark matter such as the supersymmetric particles and the axion. The halo dark matter density profile of many galaxies such as our Milky way galaxy, a class of galaxies called dwarf galaxies, another class called low surface brightness galaxies have been studied. They all show a core density which is much softer and flatter rather than "cuspy" as theoretically expected. Of special interest are the studies of dwarf speroidal galaxies which are known to be dark matter dominated, unlike the spiral galaxies, like our own, which are known to have dense baryonic cores in the form of bars, which could be confusing the observations. We will refer to this as the core density puzzle.

Two astrophysicists from Princeton, Spergel and Steinhardt have recently revived an old idea (considered in the mid 80's and dumped as not being very useful), that dark matter may be strongly self interacting, to resolve this puzzle. They argue that, if there is scattering among the dark matter particles, then as they start settling towards the center when the matter is cold, the center will become dense and will lead to scattering of the particles which will generate heat that will drive the particles away from the center. This will then prevent the dark matter density at the core from being excessive. Specifically they note that if the dark matter particle has mean free collision path of about a kpc to a Mpc, then the core on this scale cannot "keep on accumulating" dark matter particles, since these will now scatter and "diffuse out". For typical dark matter particle densities of order of one particle per cm^3, this requires a cross section for scattering of $\sigma \simeq 10^{-21} - 10^{-24}$ cm^2. As mass of the DM particle increases, the density will go down and the cross section can be proportionately larger. These cross sections are of the same order as nuclear cross section.

Furthermore the properties of the dark matter particle must be such that it must not allow for dissipation of the thermal energy via emission of light particles; otherwise,the galactic core would cool and lead to an increase in core density.

As far as the microlensing objects go, they cannot be dark matter stars if axions or the supersymmetric particles are the dark matter constutuents, since they do not have self interaction to bind together in small clumps. The question then is whether the half solar mass microlensing objects are simply made of familiar matter. It has been argued by K. Freese, D. Graff and Fields that there are considerable amount of difficulty in understanding the microlensing observations within the framework of conventional astronomy. The main problem is that a normal compact object made of protons, neutrons and electrons with mass in the half solar mass range is above the ignition limit and will shine. It cannot be a blackhole since they are expected to be heavier than the Chandrasekhar mass i.e. 1.4 $M_{\odot}$. The so called brown dwarfs are lighter than a solar mass. The only possible candidate is a dim, old white dwarf. But this possibility requires that there must be lot of heavy elements like carbon, silicon etc in the galaxy which ought to have been ejected by the old white dwarfs and there is no evidence for such high abundance of these elements in our galaxy. One is therefore faced with a real puzzle.

4 Mirror matter models

The mirror matter models that duplicate the familiar universe of matter and forces have a long history. They were first mentioned briefly in the celebrated nobel prize winning parity violation paper by Lee and Yang and has subsequently been discussed by many authors. Interest in these models were revived in the mid 80's by the superstring theories, since they picked these classes of models in a ten dimensional universe prior to the Planck epoch, as the only consistent ones. As a result, if the mirror structure survives the process of compactification of the extra dimensions, one obtains the kind of four dimensional mirror models under discussion here.

The recent results in the arena of neutrinos have led several of us to revive these theories. To appreciate the reason for this, note the well known fact that the standard model has three generations of matter each with identical strong, weak and electromagnetic properties, but with very different masses. Each generation has one neutrino in it. Therefore, there are a total of three neutrinos in nature. The fact that there no more neutrinos have been confirmed by experiments at the CERN (Geneva) and the Stanford accelerators. On the other hand a different message seems to be emanating from the recent neutrino oscillation experiments.

There are apparently three separate evidences for the oscillation of neutrinos from one species to another: the oldest from the attempts to observe solar neutrinos where a confirmed deficit by five experiments- Kamiokande in Japan, Super-Kamiokande in Japan, Gallex in Italy, SAGE in Russia and a Salt mine experiment in Homestake, USA has been successfully interpreted as an oscillation of electron neutrinos to some other species of neutrinos. Crucial to the confirmation of this deficit are the classic

solar model calculations by John Bahcall of Princeton, which has subsequently been confirmed by many others.

The second evidence for neutrino oscillation is the deficit of cosmic ray muon type neutrinos observed by Super-Kamiokande in Japan and confirmed by several other experiments, such as the one in Soudan mine in the US and MACRO experiment in Italy.

The third one is more controversial- it is a laboratory observation of oscillation of muon type neutrinos to electron type neutrinos by a group at Los Alamos in USA. Experiments to confirm this are under way at Rutherford laboratory and are in the planning stage at Fermilab in the US.

At present there is a crisis if all the three experiments are correct. This comes from the fact that there is no way to understand all the existing observations of neutrino oscillations if there only three neutrinos. It was therefore suggested by D. Caldwell and I (and independently by J. Peltoniemi and J. Valle) in 1993 that one introduce an additional neutrino species. However, if this extra neutrino has to be consistent with the data from accelerators which have confirmed the three neutrino picture, than the extra neutrino species must be very different from the known neutrinos $(\nu_e, \nu_\mu, \nu_\tau)$. In particular, it must interact very weakly with the known neutrinos. It is therefore called a sterile neutrino.

One must then seek to understand this extra neutrino within the framework of the known laws of particle physics. The simplest possibility is to postulate that the extra "sterile" neutrino is from the duplicate mirror world, which should have its three neutrinos like ours. Like the familiar neutrinos, they must have tiny mass, which should be caused by the same mechanism that caused our neutrinos to have tiny mass. This was the idea proposed by Zurab Berezhiani and I and independently by two Australian physicists, Robert Foot and Ray Volkas in 1995. There were however differences between the two suggestions. We proposed that the two sectors of the universe differ in only one way by the fact that the masses of the particles are different in them whereas the Australian group proposed that they be same. This is a fundamental difference which has been by V. Teplitz and I to apply this model to understand dark matter anomalies, that I describe below. The interesting point is that the lack of definitiveness in the neutrino data at present does allow the two possibilities for the profile of the mirror world; therefore as neutrino data improve, one will know for sure which of the two (if any) presents the true picture of nature.

Relevant to the question of dark matter is the feature of these models that the mirror particles interact only with the mirror photons and not the familiar photons; hence they remain dark to our observations. Since the lightest particles of the mirror sector (other than the neutrinos), the mirror proton and the mirror electron (like those in the familiar sector) are stable and are expected to have abundances similar to the familiar protons and electrons, the proton being heavier could certainly qualify as a dark matter candidate. We elaborate on these comments later in this article.

The asymmetric mirror model is characterized by one parameter, the mass ratio $m_{p'}/m_p = \zeta$. A value of $\zeta \sim 10 - 30$ is required to explain the neutrino puzzles.

What is more interesting is that for the same parameter range required to solve the neutrino puzzles, mirror matter can also provide an explanation of the microlensing observations- in particular why the observed MACHOs have a mass very near the solar mass and are still dark.

Let us start with a discussion of the mirror matter models. The basic idea of the model is already alluded to earlier i.e. *duplicate the standard model or any extension of it in the gauge symmetric Lagrangian and allow for the possibility that symmetry breaking may be different in the two sectors.* (See table below) There is an exact mirror symmetry connecting the Lagrangians (prior to symmetry breaking) describing physics in each sector. Clearly the $W's, \gamma's$ etc in each sector differ from those in the other as do the quarks and leptons. When the symmetry breaking scale is different in the two sectors, we will call this the asymmetric mirror model. The QCD scale being an independent scale in the theory could be arbitrary. We will allow both the weak scale and the QCD scale of the mirror sector to differ from those of the familiar sector and assume the same common ratio ζ for both scales i.e. $< H' > / < H >= \Lambda'/\Lambda \equiv \zeta$.

$$u,\ d,\ e,\ \nu_e \quad \leftrightarrow \quad u',\ d',\ e',\ \nu'_e$$

$$W,\ Z,\ \gamma,\ G \quad \leftrightarrow \quad W',\ Z',\ \gamma',\ G'$$

$$\phi, \nu_R, \ldots \quad \leftrightarrow \quad \phi',\ \nu'_R, \ldots$$

←Gravity→

It is assumed that the two sectors in the universe are connected by only gravitational interactions. It was shown in that gravity effects such as those due to black holes can generate mixings between the familiar and the mirror neutrinos. This is one of the ingredients in the resolution of neutrino puzzles.

In discussing cosmology, we first note that both sectors of the universe will evolve according to the rules of the usual big bang model except that the cosmic soups in the two sectors may have different temperature. In fact the constraints of big bang nucleosynthesis require that the post inflation reheat temperature in the mirror sector T'_R be slightly lower than that in the familiar sector T_R (define $\beta \equiv T'_R/T_R$) so that the contribution of the light mirror particles such as ν', γ' etc. to nucleosynthesis is not too important. This is due to the fact that extensive analyses to date show that if the present abundances of Helium, deuterium and Lithium in the universe are to be understood from first principles in a big bang picture, one cannot allow more than four neutrino like light objects. In a mirror universe theory, there will six such particles and when the mirror photon is included it becomes slightly over seven. Thus a cooler mirror universe is essential to the viability of these theories. This inflation mechanism referred to above is called asymmetric inflation and can be implemented in different ways. We will see that, if we want the mirror nucleons to play the role of the dark matter, we will need a definite value of temperature of the mirror universe

depending on the choice of ζ, the mass ratio of nucleons in the two sectors. This in turn will help us to predict a value for the equivalent extra neutrinos at the BBN epoch (i.e. δN_ν) which can be used as a test of this model.

Before detailed discussion, let us first note the impact of the asymmetry on physical parameters and processes. First it implies that $m_i \to \zeta\, m_i$ with $i = n, p, e, W, Z$. This has important implications for the nuclear and atomic physics of the mirror sector. For instance, the binding energy of mirror hydrogen is ζ times larger so that the recombination of proton and elctron to hydrogen in the mirror sector takes place much earlier than in the visible sector. This is well knwon to play a crucial role in any possible understanding of galaxy formation in the universe. With $\beta \equiv T'_R/T_R$ as above, the mirror recombination occurs when the temperature of the familiar sector is $\zeta/\beta T_r$ where T_r is the recombination temperature in the familiar sector. The mirror sector recombination takes place before familiar sector recombination; this means that density inhomogeneities in the mirror sector begin to grow earlier and familiar matter can fall into them later as in typical cold dark matter scenarios.

5 Mirror nucleon as dark matter

Let us show why under the conditions described above, the mirror matter can provide a dark matter candidate. The particle that is the candidate for the dark matter of the universe is the mirror proton since it is a stable particle and is about 20 to 30 times heavier. Since we have assumed that forces in the mirror sector are the same as in our sector, matter antimatter asymmetry in both sectors should be of the same order (perhaps even equal). One can then compute the contribution of mirror baryons to the mass density of the universe (expressed as $\Omega_m \equiv \rho_m/\rho_{critical}$) as follows:

$$\frac{\Omega_{B'}}{\Omega_B} \simeq \beta^3 \zeta \tag{1}$$

where the β^3 factor comes from the fact that the mirror sector is cooler than the familiar sector by a factor β and ζ comes from the fact that mirror baryon is heavier by a factor ζ compared to the baryons in the familiar sector. Here we have assumed as stated before, that baryon to photon ratio in the familiar and the mirror sectors are the same as would be expected since the dynamics are same in both sectors due to mirror symmetry. Eq. (2) implies that both the baryonic and the mirror baryon contribution to Ω are roughly of the same order, as observed. This provides a resolution of the first conceptual puzzle. Furthermore if we take $\Omega_B \simeq 0.05$, then $\Omega_{B'} \simeq 0.2$ would require that $\beta = (4/\zeta)^{1/3}$.

Clearly to satisfy the inflationary constraint of $\Omega_{TOT} = 1$, we need $\Omega_\Lambda \simeq 0.7$. These kinds of numbers for cold dark matter density apparently emerge from current type I supernovae observations. Thus, mirror baryons seem to have just the right properties to be the cold dark matter of the universe.

6 Explaining the microlensing anomaly

Let us now turn to show how the mirror model accounts for the microlensing observations. Clearly, since the mirror sector is similar to our sector of the universe, all astrophysical objects will have their mirror counterparts. This includes the stars, planets, blackholes as well as galaxies. In this section, we focus on the mirror stars. The reason for this is that as stated before, there seems to be no simple way to understand the dark objects observed in the Milky way galaxy with masses of order of half the solar mass. The conjecture was made by Russian physicist S. Blinnikov that perhaps, they could be mirror stars. However a specific calculation needed to be done to see if the mirror star masses come out in the desired range. This was carried out by V. Teplitz and I in 1999. We found by a very simple reasoning that maximum mass of the mirror stars are smaller by a factor ζ^2 compared to the maximum mass of stars in the familiar sector. To see this how this ζ dependence comes out in a simple way, note that typical mass of a star in the familiar sector is given by $M_\odot \simeq A(G_N)^{-3/2} m_p^{-2}$, where G_N is Newtons constant and A is a parameter that reflects the details of stellar dynamics and is somewhere around 1-100. Once we go to the mirror sector, the proton mass changes to ζm_p giving the scaling law described above. It is well known that maximum mass of stars in our sector of the universe is around 100 times the mass of the Sun. Therefore, using the above scaling law and using $\zeta \sim 15$, we would get maximum mass of mirror stars to be about half a solar mass. This provides a rather clean explanation of the microlensing anomaly.

We want to point out here that we do not expect all of mirror matter to condense to form mirror stars. We would expect our dark matter in the form of a mixture of mirror dust and mirror stars. In this connection, it has been noted recently that current upper limits to scattering optical depths for Thomson scattering suggests that the compact mirror objects cannot be the main dark matter constituent.

7 Self interaction of mirror matter and halo core density problem

As noted in the introduction, there appear to be indications from the core density profile of dwarf and low surface brightness galaxies that the dark matter may need to be endowed with a significant self interaction. According to the analysis of Spergel and Stenhardt, the self interaction must be such that the collision cross section of dark matter particles should be of order $10^{-21} - 10^{-23}$ cm^2 for a one GeV particle corresponding to a DM mean free path of order of $\lambda_{ss} = 3 - 300$ kpc in a gas with number density given by ρ_{DM}/m. Also we note that the cross section would scale linearly with the mass of the dark matter particle. The mean free path requirement cannot be met by the neutralino or the axion but is met quite naturally by the mirror dark matter forces.

Two obvious kinds of self interactions are the self interactions due to inter-atomic forces and nuclear forces. The latter are not very effective as can be seen by the following crude argument. From pure ζ scaling, we can infer that $\sigma_{N'N'} \approx \sigma_{NN}\zeta^{-2}$.

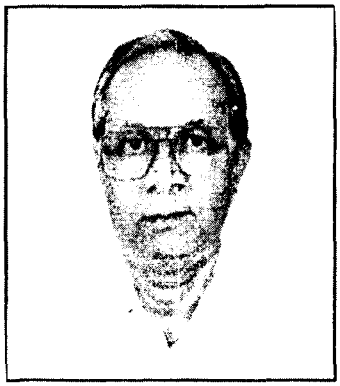
The value of $\zeta = 20$ would put the mirror nucleon cross section to be of order 10^{-26} cm^2, which is much too small. Note that for $\zeta = 20$, one would need a cross section of order 10^{-22} cm^2 to get $\lambda = \lambda_{ss}$. On the other hand, one would expect that there can be scattering of the dark matter particles (mirror atoms) due to inter-atomic forces. A crude estimate of such cross sections is given by $\sigma_{H'H'} \approx \pi\ (a'_0)^2$, where a'_0 is the Bohr radius of the mirror hydrogen atom. One can then estimate the mean free path of the dark matter particles in the mirror model to be $\lambda_{DM} \approx 3\pi\zeta^3 \times 10^{16}$ cm. For $\zeta = 20$, this gives $\lambda_{DM} \approx 0.3$ kpc, which is not far below the required values for explaining the halo core density profile. Note that Spergel and Steinhardt require $\lambda_{DM} \approx$ kpc to mpc. On the other hand, one could take the value of $\zeta = 30$ and thereby get $\lambda \approx$ one kpc.

It would thus appear that mirror dark matter presents the best scenario for understanding the halo core density profile using a self interacting dark matter model. Of course more detailed numerical work is needed to confirm these qualitative conclusions.

8 Conclusion

In this article, we have presented an unconventional picture of the universe motivated by several theoretical as well as expermental discoveries. We have argued that there is a need for having a parallel sector of the universe if we want to understand a plethora of new phenomena in the neutrino as well as as cosmological domain in a unified manner. In the scientific literature, this is known as the so called asymmetric mirror universe model. This was originally proposed to solve neutrino puzzles and subsequently advocated as providing an alternative dark matter candidate. More recently it has been realized that it may have the potential to resolve the apparently anomalous microlensing observations and possibly the core density problem of dark halos. Possible tests of these models are to narrow the allowed values of δN_ν from more accurate observation of deuterium, He^4 and Li^7 and observing whether further accumulation of MACHO candidates lie in the mass between 0.1- 1 solar mass. If this hypothesis is borne out by future research, it would revolutionize our thinking about the universe- it would imply that completely unbeknownst to us, we exist side by side with a vast unseen duplicate of our own universe, with far reaching philosophical as well as scientific implications. One must therefore turn attention to study this new cosmology and pinpoint further tests. Needless to say that if the underground searches for the cold dark matter now under way lead to a positive signal, mirror matter cannot be the dominant component of the dark matter of the universe. It would of course not rule out the general idea that there may be a parallel universe.

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Inertial Forces: á la Newton in General Relativity

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1 Introduction

The Universe as we know, seem to be governed by four fundamental forces of which 'Gravity' the weakest is the most dominant, binding all forms of matter with mutual attraction. Though it should have been a very common experience for anyone to feel the pull of gravity while climbing a fleet of stairs or going uphill, it required the genius of Newton to identify this force of attraction exerted by Earth and further generalise the idea to an universal law. Of course, as mentioned by Newton himself, his discovery of the 'inverse square law' was facilitated by the already discovered empirical laws of Kepler regarding the motion of planets around the Sun, and his own three laws of motion, which form the basis of classical mechanics.

As is well known, Newtonian physics works extremely well in weak gravitational fields and for small velocities and thus can successfully explain phenomena both locally and at galactic scales, with the three important forces referred to as inertial forces:

1. Gravitational, proportional to the gradient of a potential,
2. Centrifugal, proportional to the square of the velocity, and
3. Coriolis, arising due to rotation of the central source.

What happens when one encounters very high speeds or intense gravitational fields?

As far as very high speeds are concerned the difficulty arose in the late 19th century, when Maxwell propounded the laws of electromagnetism which are not consistent with Galilean relativity based on Newtonian mechanics. The problem was essentially due to the Newtonian perception of absolute time, which allowed for propagation of action with infinite velocity. Einstein thus rejected the notion of absolute time and considered the space-time framework for his Special Theory of Relativity and successfully gave a framework to discuss the electrodynamics in moving frames, which are inertial in the sense that they do not oblige non-uniform acceleration. Special Relativity indeed got the role of a fundamental theory for modern physics alongwith quantum mechanics. However, gravity could not be discussed within the framework of special relativity due to the fact that the light which is affected by gravity would travel along paths which are not straight in the sense of a flat manifold which confines special relativity. Thus, Einstein had to look for a more general geometrical framework to describe gravity which was achieved through the General Theory of Relativity described on the curved Remannian manifold covariantly for all observers

with gravitation being identified with space-time curvature. It is indeed remarkable that the General Theory of Relativity successfully filled in whatever lacuna the Newtonian theory had and in the approximation of weak fields reduced to Newtonian prescription. As Einstein's equations of GTR related the geometry of space-time with the energy-momentum distribution of matter describing the physics, the theory has been termed as Geometrisation of Physics Whereas in other theories the equations of motion have to be separately prescribed, Einstein's equations automatically express the equations of motion through the conservation laws which are again automatically satisfied due to certain identities that go with the background manifold.

Thus, for a free particle, acting only under the influence of gravity the equations of motion are given by the geodesics of the given space-time manifold describing the gravitational field. In fact, aesthetically this is a very beautiful and self-consistent approach to describe physics wherein the old concept of 'forces' appears irrelevant. However, much as one admires the language of geometry, the question is, does one get all the information inherent in the system or is there something overlooked or missed in the interpretation? Further, the language of forces has indeed been very useful in discussing other interactions, and thus it could be useful to bring back the concept of forces within the geometry of general relativity so that one can quantify the non-Newtonian features inherent in the geometry more explicitly. This would be particularly true for studying aspects very close to ultra compact objects like black holes, a region which is never available for Newtonian physics.

2 Formalism

As the idea is to bring in Newtonian language into a geometric theory of space-time, one needs to slice the 4-space into a (3 space + time) structure and look at the features on the absolute 3 space so obtained. In fact, such a 3+1 split of space-time is nothing new in general relativity, as, long ago Arnowitt, Deser and Misner (1962)[1] introduced such a scheme while looking for a method to give a Hamiltonian description of general relativity. As Misner, Throne and Wheeler (1972)[2] mention, "*The slicing of space-time into a one parameter family of space-like hyper surfaces is called for, not only by the analysis of the dynamics along the way, but also by the boundary conditions as they pose themselves in any action principle of the form - give the 3-geometries on the two faces of a sandwich of space-time and adjust the 4-geometry in between to extremize the action*".

In fact, such a procedure of studying the dynamics effectively paved the way for setting up numerical methods to study evolution equations of the Cauchy data given on an initial hyper surface, and thus became a standard procedure for numerical relativity [3, 4].

Instead of a fully dynamical system, suppose one has a stationary system wherein a time-like Killing vector exists then one can get a lower dimensional quotient space through an isometry group action and one can study certain dynamical features within a given geometrical background. Abramowicz, Carter and Lasota (1988, hereafter

referred to as ACL) [5] used such a prescription with a conformal rescaling factor and showed that one can indeed obtain a 3+1 splitting wherein the 3-space is the quotient space obtained from the action of the time-like Killing vector and the metric conformal to the spatial geometry of the original four-space. As they realised the most significant feature of a conformal reslicing was that the normally geometrical geodesic equation for a test particle would separate into language of Newtonian forces wherein one can directly interpret terms as gravitational, centrifugal and Coriolis accelerations.

Abramowicz, Nurowski and Wex (1993, hereafter referred to as ANW) [6, 7] later gave a covariant approach to this formulation which does not depend upon any particular symmetry and is as follows:

In the given space-time manifold M with the metric

$$ds^2 = g_{ij} dx^i dx^j \tag{1}$$

introduce a congruence of world lines which is globally orthogonal to t = const., hypersurface which ensures that the vorticity of the congruence to be zero. In fact, Bardeen (1972) [8] adopted such a congruence in axisymmetric, stationary spacetimes defining what are called locally non-rotating observers or zero angular momentum observers (ZAMO). The advantage of having such a congruence is that these local observers 'rotate with the geometry' and the connecting vectors between two such observers with adjacent trajectories do not precess with respect to Fermi-Walker transport. Denoting such a vector field by n^i ($n_i n^i = -1$ time-like) it can be verified that the corresponding four-acceleration is proportional to the gradient of a scalar potential.

$$n^k \nabla_k n_i = \nabla_i \phi \, ; \quad n^i \nabla_i \phi = 0 \tag{2}$$

Though the vector field n^i is not uniquely determined by (2), locally each particular choice of n^i uniquely defines a foliation of the space-time into slices each of which represents space at a particular instant of time, whose geometry is given by

$$h_{ik} = g_{ik} + n_i n_k \, ; \; h^i{}_k = \delta^i{}_k + n^i n_k \tag{3}$$

(2) also ensures that the special observers n^i see no change in the potential as their proper time passes by and thus have fixed positions that help them in distinguishing between different 'inertial forces'.

Consider a particle of rest mass m_o and four-velocity U^i, which can be expressed as

$$U^i = \gamma \left(n^i + v\tau^i \right) \tag{4}$$

wherein τ^i is the unit tangent vector (space-like) orthogonal to n^i and parallel to the 3-velocity v of the particle in the 3-space (Lorentz speed) and γ the Lorentz factor $\left(= \frac{1}{\sqrt{1-v^2}}\right)$. The four-acceleration of the particle a^i may now be obtained through direct computation (Abramowicz, 1993) [6]

$$\begin{aligned} a_k = u^i \nabla_i u_k = & -\gamma^2 \nabla_k \phi + \gamma^2 v \left(n^i \nabla_i \tau_k + \tau^i \nabla_i n_k \right) \\ & + \gamma^2 v^2 \tau^i \nabla_i \tau_k + (v\gamma)^{\cdot} \tau_k + \dot{\gamma} n_k \end{aligned} \tag{5}$$

Let us consider the motion of the particle in a circular orbit in a general stationary axisymmetric space-time. From the given symmetries, there exist two Killing vectors η^i the time-like having open trajectories, and ζ^i the space-like with closed trajectories. If the particle has a constant angular velocity Ω as measured by the stationary observer at infinity then its four-velocity u^i may be expressed as

$$u^i = A\left(\eta^i + \Omega\zeta^i\right) \tag{6}$$

A being the redshift factor

$$A^2 = \left[< \eta\eta > +2\Omega < \eta\zeta > +\Omega^2 < \zeta\zeta >\right]^{-1} \tag{7}$$

In terms of the Killing vectors one can express n^i and ϕ consistently as

$$n^i = e^{\phi}\left(\eta^i + \omega\zeta^i\right) , \quad \omega = - < \eta, \zeta > / < \zeta, \zeta > \tag{8}$$

and

$$\phi = -\frac{1}{2}\ell n\left[- < \eta, \eta > -2\omega < \zeta, \eta > -\omega^2 < \zeta, \zeta >\right] \tag{9}$$

From (4) and (6) one can evaluate the particle speed V to be:

$$V\tau^i = e^{\phi}(\Omega - \omega)\zeta^i \tag{10}$$

Using now the ACL approach of conformal rescaling of the 3-metric, one can define the projected metric and the vectors

$$\tilde{h}_{ij} = e^{2\phi}\, h_{ij} , \quad \tilde{\tau}^i = e^{\phi}\tau^i \tag{11}$$

such that the acceleration may now be written as

$$a_k := -\nabla_k\phi + \gamma^2 V\left(n^i\nabla_i\tau_k + \tau^i\nabla_i n_k\right) + (\gamma V)^2\tilde{\tau}^i\tilde{\nabla}_i\tilde{\tau}_k \tag{12}$$

as the last two terms in (5) become zero for a particle with constant speed, and conserved energy. $\tilde{\nabla}$ in (12) refers to the covariant derivative with respect to the metric $\tilde{h}_{ij}$. As may be seen, the acceleration is made up of three distinct terms, (i) gradient of a scalar potential, (ii) a term proportional to V, and (iii) one proportional to V^2. The first and the third terms may be immediately recognised as the gravitational and centrifugal accelerations. Further, as n^i and τ^i are parallel to the Killing vector η^i and ζ^i respectively from the equation for Lie derivative, one has

$$L_n\tau \equiv n^i\nabla_i\tau_k + \tau_i\nabla_k n^i = 0 \tag{13}$$

Using this alongwith the fact that n^i and τ^i are orthogonal, the second term of (12) may be written as

$$\gamma^2\left[n^i\left(\nabla_i\tau_k - \nabla_k\tau_i\right)\right] \tag{14}$$

which represents the Lense-Thirring effect of the inertial drag and thus identified as the generalisation of the Coriolis acceleration.

If the general axisymmetric and stationary space-time is represented by the metric

$$ds^2 = g_{tt}dt^2 + 2g_{t\phi}dtd\phi + g_{\phi\phi}d\phi^2 + g_r dr^2 + g_{\theta\theta}d\theta^2 \tag{15}$$

with g_{ij}s being functions of r and θ only then the total force acting on a particle in circular orbit with constant speed Ω may be expressed as [9]

$$F_i := (Gr)_i + (Co)_i + (Cf)_i \tag{16}$$

wherein

$$\begin{aligned}(Gr)_i &: = -\nabla_i \phi = \tfrac{1}{2}\partial_i \left\{\ell n \left[\left(g_{t\phi}^2 - g_{tt}g_{\phi\phi}\right)/g_{\phi\phi}\right]\right\} \\ (Co)_i &: = \gamma^2 V n^k \left(\nabla_k \tau_i - \nabla_i \tau_k\right) \\ &= -a^2(\Omega - \omega)\sqrt{g_{\phi\phi}}\left\{\partial_i\left(\frac{g_{t\phi}}{\sqrt{g_{\phi\phi}}}\right) + \omega \partial_i \sqrt{g_{\phi\phi}}\right\}\end{aligned} \tag{17}$$

and

$$\begin{aligned}(Cf)_- &= (\gamma V)^2 \tilde{\tau}^k \tilde{\nabla}_k \tilde{\tau}_i \\ &= -A^2(\Omega - \omega)^2 \frac{g_{\phi\phi}}{2}\pi_i \left\{\ell n \left[g_{\phi\phi}^2 \middle| \left(g_{t\phi}^2 - g_{tt}g_{\phi\phi}\right)\right]\right\}\end{aligned} \tag{18}$$

with

$$\Phi = -\frac{1}{2}\ell\left[-g_{tt} - 2\omega g_{t\phi} - \omega^2 g_{\phi\phi}\right] \; ; \; \omega = -g_{tq}/g_{\phi\phi}$$

and

$$A^2 = -\left[g_{tt} + 2\Omega g_{t\phi} + \Omega^2 g_{\phi\phi}\right]^{-1} \tag{19}$$

In order to understand this splitting of the total force, let us consider the simple case of static spacetimes [10]. Then, by definition the Coriolis term would be absent, and the force acting on a test particle of mass m_o and 3-momentum p^α is given by (ACL)

$$m_o \tilde{f}_\alpha = \tilde{p}^\mu \tilde{\nabla}_\mu \tilde{p}_\alpha + \frac{m_o^2}{2}\tilde{\nabla}_\alpha \phi \tag{20}$$

wherein $\tilde{p}^\mu = m_o V \gamma \tilde{\tau}^\mu$ and thus consistent with what one gets from (15) in the projected 3-space. It is now clear that in the static space time, the trajectories of photons (rest mass zero particle) are given by the curves

$$\tilde{\tau}^\mu \tilde{\nabla}_\mu \tilde{\tau}_\alpha = 0 \tag{21}$$

which by definition are geodesics of this 3-space. Thus, one finds that the 'null trajectories' of the 4-space project onto the geodesics of the quotient space obtained through conformal slicing and indicates that particles on these trajectories do not experience any 'force' in the Newtonian sense.

It is for this reason that ACL called this slicing as optical reference geometry meaning that the null lines project onto straight lines in the Euclidean sense. However,

as was seen later this is true only for static spacetimes, as rotation would influence the photons differently for prograde and retrograde motion. In static spacetimes, one finds that particles acted on by forces other than gravity would deviate from the geodesics of the quotient 3-space obtained by conformal slicing, as these geodesics behave like straight lines of Newtonian geometry and thus follow Newtonian laws of motion.

The most important aspect of the frmalism is that while the particle kinematics is expressed in Newtonian language, the general relativistic effects are all present and thus help in understanding results which were earlier known in general relativistic analysis but were hidden in the geometry and not accessible for visualisation.

3 Specific Applications

We start from the simplest application of the methodology outlined above to study the particle kinematics in the static spacetimes, taking the Schwarzschild geometry as the first example (Abramowicz and Prasanna, 1990; hereafter referred to as AP)[10].

The metric as expressed in the usual coordinates,

$$ds^2 = -\left(1 - \frac{2m}{r}\right) dt^2 + \left(1 - \frac{2m}{r}\right)^{-1} dr^2 + r^2 \left(d\theta^2 + \sin^2\theta d\phi^2\right) \tag{22}$$

would yield for the gravitational and centrifugal accelerations, acting on a test particle in circular orbit, the expressions:

$$(Gr)_r = \frac{m}{r^2}\left(1 - \frac{2m}{r}\right)^{-1} \tag{23}$$

and

$$(Cf)_r = -\Omega^2 r\left(1 - \frac{2m}{r}\right)^{-1}\left(1 - \frac{2m}{r} - \Omega^2 r^2\right)^{-1}\left(1 - \frac{3m}{r}\right) \tag{24}$$

From (24) it is clear that while (Gr) and (Cf) are in opposite directions upto $r = 3m$ from infinity for $r < 3m$ they both have the same direction. As gravitational acceleration is always undirectional, it is clear that the centrifugal acceleration reverses its sign at $r = 3m$. In fact, if one looks at the photon effective potential in the Schwarzschild geometry, one finds that $r = 3m$ is the location of the maximum and thus corresponds to unstable circular orbit. What has been noticed now is that this null line is the straight line path for the photon in the quotient space and thus corresponds to a location at which the centrifugal acceleration is zero, and on either sides the centrifugal force acts in opposite directions.

As shown in AP, this feature has important kinematical implications in the study of accretion flows near ultra compact objects (black holes) like the Rayleigh criterion for stability of flow turns out to be

$$\frac{2m\left(r^3 - 2mr^2\right)}{\left(r^3 - \ell^2 r + 2m\ell^2\right)^2}\left(1 - \frac{3m}{r}\right)\frac{d\ell^2}{dr} > 0 \tag{25}$$

This means $\frac{d\ell^2}{dr} > 0$ for $r > 3m$ and < 0 for $r < 3m$, indicating that for $r < 3m$ the angular momentum has to be advected inwards for stability. In fact, this result clearly explained the findings of Anderson and Lemos (1988)[11], who had obtained inward advection of angular momentum very close to black holes.

Another important implication of centrifugal reversal is borne out in the evaluation of ellipticity of slowly rotating fluid configuration represented by a sequence of quasi-stationary solutions, with decreasing radii, keeping the mass and angular momentum conserved. Chandrasekhar and Miller (1974) [12] had considered this problem and found that the ellipticity instead of increasing continuously, reached a maximum, a result which they had attributed to frame dragging of rotating systems. However, after the discovery of centrifugal reversal, Abramowicz and Miller (1990)[13] analysed the equilibrium configuration in general relativity using the 'inertial forces' approach and found that the equilibrium demands

$$\begin{aligned} \frac{GM}{R^2} &= R\Omega_k^2 \left(1 - \frac{3m}{R}\right)\left(1 - \frac{2m}{R} - R^2\Omega_k^2\right)^{-1} \\ \Omega_k^2 &= \frac{GM}{R^3} \end{aligned} \tag{26}$$

which to the lowest order in Ω gave the ellipticity function to be

$$\epsilon(R) = \frac{125}{32}\left[1 - \frac{3}{2R}\right]\left(\frac{1}{R}\right) \tag{27}$$

exhibiting a maximum at $R = 3$.

Though they had obtained the ellipticity maximum, the lacuna in their approach was that they had used only the Schwarzschild exterior geometry for evaluating the inertial forces. Prasanna and coworkers (A. Gupta, S. Iyer and A.R. Prasanna (1996)) [14] reconsidered this problem starting from the general conservation laws expressed in the 3+1 formalism and using the Hartle-Thorne approximation solution for the interior of a slowly rotating body. Defining the ellipticity through force balance equations at the pole and equator

$$e^2 = 1\frac{(F_{cf} - F_{ge})}{F_{gp}}\ , \quad \epsilon \approx \frac{e^2}{e} \tag{28}$$

(F_{ge} is the gravitational force at the equator and F_{gp} at the poles) they found the maximum to occur at $r = 5.4m$, which is much closer to Chandrasekhar-Miller result of maximum occurring at $r = 5m$.

Prasanna (1991) [15] had considered another static spacetime viz. Ernst space-time which represents the external field of a black hole immersed in a uniform magnetic field. The photon effective potential in this metric has two extrema, the maxima corresponding to the unstable orbit very close to $r = 3m$, while a minima located far away, governed by the strength of the magnetic field and yielding a stable photon orbit. As centrifugal force would go to zero at both these locations, it appears that the Newtonian orbits are possible only within the region bounded by these two points of extrema.

We next consider the situation in the Kerr geometry which is actually supposed to be the space-time exterior to a rotating black hole represented by the metric

$$\begin{aligned} ds^2 = &\left(1 - \tfrac{2mr}{\Sigma}\right) dt^2 - \tfrac{4amr}{\Sigma} \sin^2 \theta dt d\phi + \tfrac{\Sigma}{\Delta} dr^2 + \Sigma d\theta^2 \\ &+ \tfrac{B}{\sigma} \sin^2 \theta d\phi^2 \end{aligned} \tag{29}$$

with

$$\begin{aligned} \Delta &= r^2 - 2mr + a^2 \\ \Sigma &= r^2 + a^2 \cos^2 \theta \\ B &= (r^2 + a^2) - \Delta a^2 \sin^2 \theta \end{aligned}$$

Using the formluae presented in (16)-(18), one can get [9]

$$(GR)_r = \frac{m\left(a^2 \Delta + r^4 + a^2 r^2 - 2ma^2 r\right)}{r \Delta \left(r^3 + a^2 r + 2ma^2\right)} \tag{30}$$

$$(Cf)_r = \frac{-(\Omega - \omega)^2 \left[r^5 - 3mr^4 + a^2\left(r^3 - 3mr^2 + 6m^2 r - 2ma^2\right)\right]}{r^2 \Delta \left[1 - \Omega^2 \left(r^2 + a^2\right) - \left(\frac{2m}{r}\right)(1 - \Omega a)^2\right]} \tag{31}$$

$$(Co)_r = \frac{2ma(\Omega - \omega)\left(3r^2 + a^2\right)}{r\left(r^3 + a^2 r + 2ma^2\right)\left[1 - \Omega^2\left(r^2 + a^2\right) - \left(\frac{2m}{r}\right)(1 - \Omega a)^2\right]} \tag{32}$$

One can immediately see the difference in the nature of centrifugal and Coriolis forces, whereas the Coriolis depends on the coupling of the angular momentum of the central source with that of the particle $a(\Omega - \omega)$, the centrifugal can go to zero at different locations solely depending upon 'a' due to the zeros of the quintic equation

$$r^5 - 3mr^4 + a^2\left(r^3 - 3mr^2 + 6m^2 r - 2ma^2\right) = 0 \tag{33}$$

It may be easily seen that for $0 < a < 1$ the equation (32) at best can have only three real roots of which, one is always definitely outside the event horizon [16] as depicted in Fig. 1. However, as also shown in this figure this location does not coincide with the location of the unstable photon orbit, prograde or retrograde. The centrifugal force vanishes at a location between the two photon orbits and for the case $a = 0$, they all coincide at $r = 3m$. Unfortunately, the direct link between the unstable photon orbit and the centrifugal force reversal, depicted in static spacetimes do not find a parallel in stationary space-time. Rotation does indeed bring in some new features of which the frame dragging is the most important one.

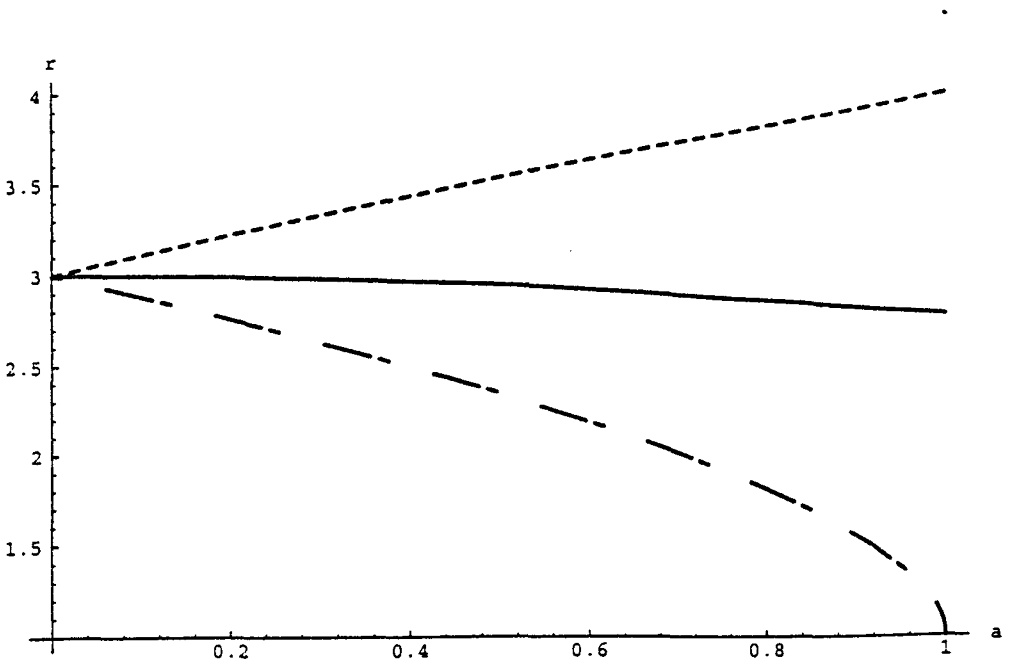


Fig. 1. Location of the point where $Cfg = 0$, (— — — — — — — —), retrograde photon orbit (- - - - -) and of the prograde photon orbit (-- -- --) for different values of a.

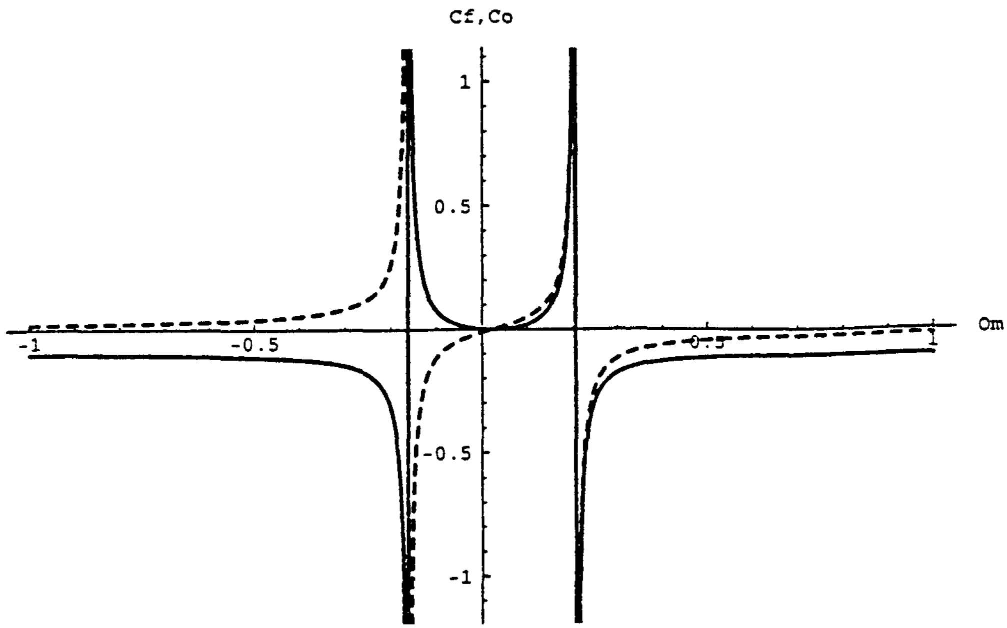


Fig. 2. Centrifugal (——) and Coriolis (- - -) force plots for $a = 0.5$, along the retrograde photon orbit for $-1 < \Omega < 1$.

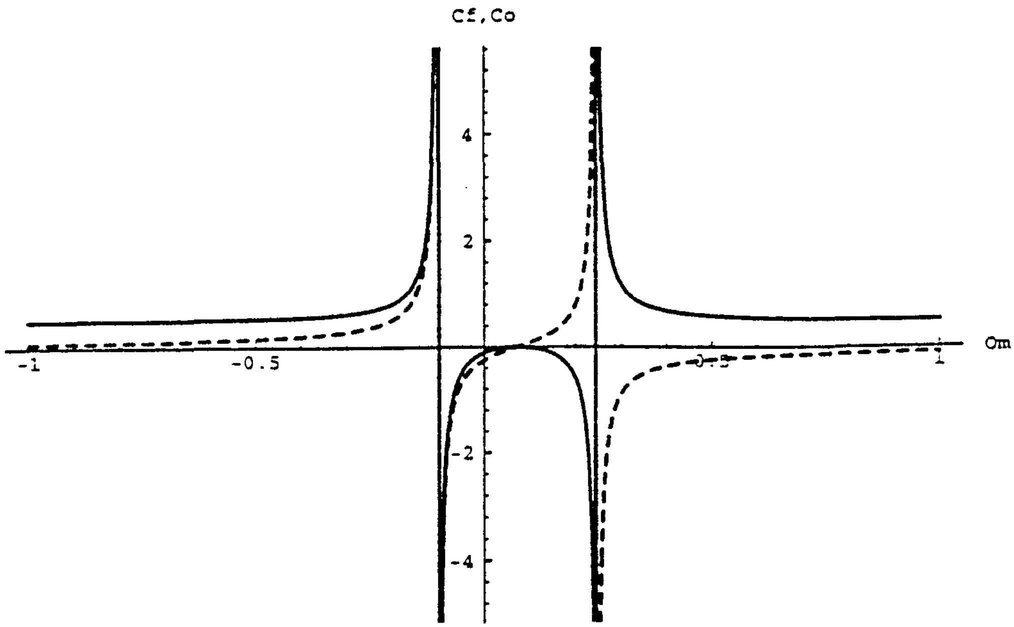


Fig. 3. Same as (2) at the prograde photon orbit.

Figs. 2 and 3 show the nature of the centrifugal and Coriolis forces at the location of retrograde and direct photon orbits as a function of Ω for $a = 0.5$. The first impression that one gets is that these forces change sign for different values of Ω across the asymptotes. However, one has to check that the asymptotes are caused by the infinity of the redshift factor A^2 at the roots of the equation

$$\Omega^2 g_{\phi\phi} + 2\Omega g_{t\phi} + g_{tt} = 0 \tag{34}$$

$$\Omega_{\pm} = \omega \pm \sqrt{\omega^2 - g_{tt}/g_{\phi\phi}} \tag{35}$$

Hence the only portion of the plots which is meaningful is the region corresponding to the values of Ω; $\Omega_- < \Omega < \Omega_+$. As may be seen in this region the centrifugal is positive along the retrograde photon orbit ($rph+$) are negative along the direct photon orbit ($rph-$) as it should be according to Fig. 1. On the other hand, the coriolis changes sign in both cases at the point $\Omega = \omega$, wherein centrifugal also vanishes because of the fact that the angular velocity is just equal to the dragging of inertial frames, by the space-time due to the rotation of the central object.

On the other hand, we have seen that there are locations in the given space-time, wherein the centrifugal force is zero but $\Omega \neq \omega$ and thus the Coriolis is non-zero. In view of this, Prasanna (1997) [9] defined an index of reference called the 'Cumulative Drag Index' as defined by the ratio

$$C = \frac{(Co - Gr)}{(Co + Gr)}$$

which could characterise purely the rotational feature of a space-time through its influence on a particle in circular orbit at the location where the centrifugal force is zero.

Fig. 4 shows the plot of C as a function of Ω, for a fixed a and R. As may be seen, there are two zeros and two infinities for the function. As $a > 0$, $\Omega > 0$ represents the co-rotating particles and $\Omega < 0$ represents the counter-rotating particles.

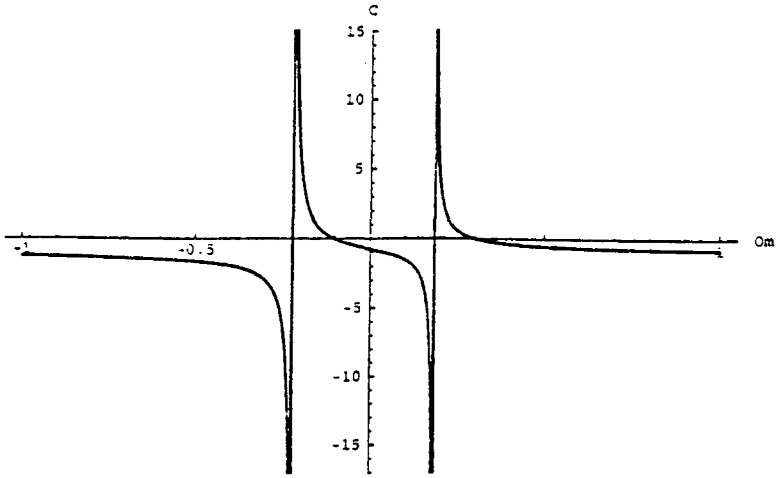


Fig. 4 Cumulative drag index C for $a = 0.5$, $R = 2.9445$ as a function of Ω $(-1 < \Omega < 1)$.

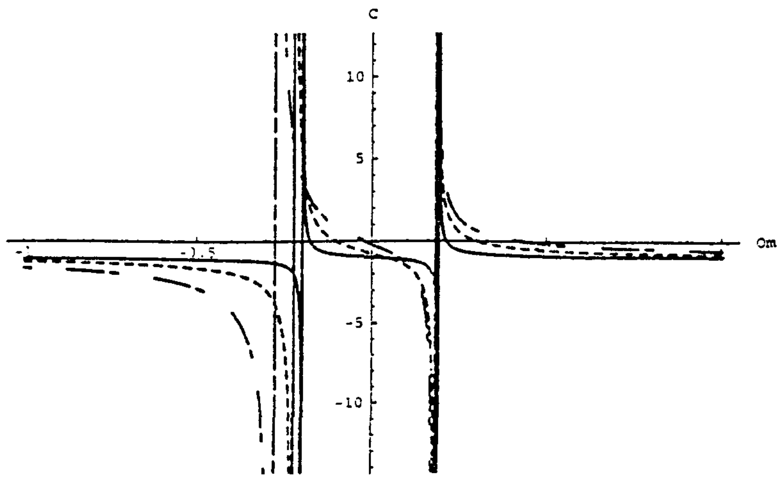


Fig. 5 C for three different values of a showing difference in Ω_- values for equilibrium orbit $(Co = -Gr)$.

As the orbit chosen is the one where the centrifugal force is identically zero the infinities of C refer to the trajectories along which the total force acting on the particle is zero as given by the definition of C. Fig. 5 shows the index C for three distinct cases of $a = 0.1$, 0.5 and 1 at the respective locations where $Cf = 0$.

It is interesting to note that as a increases, the co-rotating particles have to decrease their angular velocity Ω very little to stay in equilibrium, whereas the counter-rotating ones have to increase their Ω much more, as depicted explicitly in Table 1.

Table 1

a	R	Ω_+	Ω_-	$\lvert(\Omega_- - \Omega_+)\rvert$	ω
0.1	2.9978	0.189022	-0.1964	0.0074	0.0074
0.5	2.9445	0.180094	-0.21965	0.0395	0.0374
1.0	2.7830	0.17722	-0.27452	0.097	0.076

However, it may be seen that, the excess adjustment on the part of counter-rotating particles is essentially due to the dragging of inertial frames ω which is always in the direction of rotation of the central source. Table 1 gives the values of ω for given a and R, which matches quite closely with the difference in the corresponding Ω for given a and R, between co- and counter-rotating particles. Thus one finds that using the language of forces within the framework of general relativity, one can exactly quantify the space-time curvature effects which otherwise is hidden in the geometry.

There have been other approaches to describe particle motion in general relativity a general survey of which was provided by Bini et al. (1997)[17]. However, the conformal slicing as described above helps directly in understanding certain physical features of fluid flow configurations near extremely compact objects and also visualise the inertial drag more clearly. It would indeed be very nice if one can use this in the context of ADM formalism for Hamiltonian dynamics. This could be of direct consequence to understand the dynamical collapse of fluid configurations, through numerical approach. It is indeed very necessary to follow the collapse, particularly to see whether the centrifugal reversal that is inherent would produce the strange behaviour of the ellipticity as evidenced in the work of Chandrasekhar and Miller. A sudden change in ellipticity could indeed produce noticeable signature on the emission of gravitational radiation from a collapsing star in the final stages before it gets into a black hole. This is an open problem which could be of great interest for classical gravitation studies.

I am very happy to dedicate this article concerning Newtonian forces in general relativity to the memory of one of the great sons of India, 'Mahamahopadhyaya Samanta Chandra Sekhar' who single-handedly realised several aspects of planetary motion, through naked eye observations aided by innovative instruments which he designed himself. His genius had helped in analysing some aspects of celestial mechanics with-

out being aware of the works of Newton and Kepler, but still compare favourably well regarding positional astronomy of the present era.

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In Praise of Astronomy

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Astronomy is the cradle of all of Science.The story of how Modern Science was born from the astronomical discoveries of Galileo and how Newton succeeded in unifying Dynamics on the Earth with Dynamics in the Heavens because he had Kepler's laws in his hands, those laws themselves being abstracted from the heavenly observations of Tycho Brahe, is well-known.

Even now, any lecture on Astronomy or the Cosmos attracts young and old, experts and laymen, as no other subject would.The Mysterious Universe will continue to cast its spell for generations to come.

A personal note:It is a look through a College telescope that determined my trajectory in this life.When as a student of Intermediate Class (roughly equivalent to the present plus two), I saw the surface of the Moon marked by gigantic mountains and craters, I was taken aback and frightened.I realized there were other things in heaven and earth than were dreamt of in my philosophy.Since Science alone held the key to these "other things" I had no hesitation in my choice of what I wanted to do. I am sure many others too have been lured into Science through Astronomy.

We are now living through the Golden Age of Astronomical discoveries. The discovery of the anisotropies and fluctuations in the cosmic microwave background takes us almost to the beginning of the universe while the mapping of the supernovae at the very boundary of the universe is pointing to the acceleration of the expansion of the universe and even to the existence of a Cosmological Constant in Einstein's equation for gravity.On the other hand, nearer to us, discoveries of many planets around other stars are being made at a breathtaking speed leading one to wonder whether the discovery of extraterrestrial life is imminent. If that happens,Man's view of himself and his place in the Universe is bound to undergo another revolutionary change, comparable to the Copernican Revolution and the Darwinian Revolution.

Inspite of the tremendous attractive power of Astronomy, Indian students seem to shy away from Astronomy when it comes to choosing a career.This is a pity.A world-class radio telescope,the famed Giant Metre Wave Telescope has come up in the Indian Horizon, thanks to visionaries like Govind Swarup. But there are not enough young astronomers jumping up to catch seats there! Even the older Ooty Radio Telescope has not outlived its use.Important discoveries can still be made there by a dedicated band of astronomers.Where are they?

The Inter University Centre for Astronomy and Astrophysics under the leadership of Jayant Narlikar is doing yeoman service in the task of spreading astronomy in the country, especially in our universities.This is good augury for the future of Astronomy in India. Much more needs to be done in this direction.

One serious lacuna is the absence of astronomical teaching in Indian universities. Astronomy used to be taught as a paper in the Mathematics Departments of some Universities and this outmoded practice is perhaps still being followed. The proper home for Astronomy and Astrophysics is Physics. Astronomy and Astrophysics must be started as one of the papers in the MSc (Physics) course. More than twenty years ago, I tried to do this in the University of Madras, but the plan did not materialize. Perhaps the time is more ripe for it now. Out of the two hundred universities in the country, we must see that at least twenty universities have Astronomy included in their Physics curricula. This is essential for the success of any Astronomy project, present ones or those that may be started in the New Century.

The author would like to dedicate this article to the memory of great Indian Astronomer Samanta Chandra Sekhar.

Reprinted from *Siddhanta Darpana, A Treatise on Astronomy by Mahamahopadhyaya Sri Chandra Sekhar Simhasamaanta*, Published by Girish Chandra Vidyaratna Press, Calcutta, May 1898.

INTRODUCTION

Prof. Jogesh Chandra Ray

In his *Brhat Samhita,* Varaha-mihira enumerates the requisite qualifications of an astronomer. According to him, an astronomer should be able to explain the differences in the various *Siddhantas,* to demonstrate, with, the help of instruments, the moment of the Sun's turning to the north or to the south, and of his entering the prime vertical and the meridian, and to make calculation agree with observation.

Unfortunately, the true science of astronomy has been ousted by the pseudo-science of astrology, whose votaries are to be found in almost every town and village of India at the present day. No doubt, there are men who have committed to memory some stray couplets from *Siddhantas,* and can perhaps compute an almanac with the aid of tables. But, as **Bhaskara** has well said, an astronomer without a knowledge of spherics is what food is without clarified butter, a monarchy without its monarch, and an assembly without a speaker.

Astronomy as a science is not cultivated by those whose business it should be to do so. They would rather learn to read the thoughts of simple persons and pretend to predict future events, than dive into the mysteries of *Kalpas* and *Yugas,* far less observe the heavens. Those that have a desire to study the science have no means of doing it, while those that have the means have no desire to watch the movements of the planets. Our students of the English colleges are busy in cramming the answers to expected

questions, and our university men are too busy to have leisure to think about the revival of the indigenous sciences and arts of the country. It is not strange therefore that the mathematical science of astronomy has been relegated to the half-read, illiterate, fortune-tellers who are not ashamed to assume the title of mathematician. For, the name mathematician (गणक) has been degraded to mean only an astrologer.

In this state of indigenous sciences, it is singular to find a man born and brought up in the recesses of the hills of Orissa, far removed from all educational activity and the influence of imported western civilization, silently treading his way into such a difficult science as mathematics. It is a unique experience in the department of national development to find a man really striving after knowledge for its own sake, under difficulties whose magnitude is no less startling than the boldness of his attempt.

This is my apology for bringing before the public, a Sanskrit work written entirely in the way of our ancient *Siddhantas* and never meant to see the light. It is the life - long labour of Chandrasekhara Simha Samanta of Orissa, written in a language which few men care to study in these days of English education.

Modern Europe boasts of discoveries, one of which alone would have been the glory of the past. The science of astronomy has been developed to so great an extent as to shed a lustre on the bright records of original and patient researches in the domain of Physical Science. The telescope, the spectroscope, and last but not the least, the art of photography, have gone hand in hand in the service of

diligent workers. In these days of "scopes" and "meters", it may be thought useless to put forward the poor work of a Hindu whose education is in no way superior to that of an astronomer of pre-telescopic Europe. And there are men, too, who have thought that much nonsense has already been written about him.

Let them but calmly take stock of the present state of Hindu astronomy. Let them find out a couple of mathematicians, brought up wholly in Sanskrit studies, who can intelligently attack the intricate calculations of a solar eclipse. Nor is there any noticeable endeavour to revive the sciences. What with natural apathy, and what with want of encouragement by endowments, no addition to the stock of the world's knowledge has been made by my countrymen for many a long year. If in these circumstances something, however poor, is laid before us, something, however crude, is evolved from within, we should rejoice over it.

Whatever may be thought of the merits of the work, I regard it as a misfortune that the author has not found a man to introduce his work, better qualified than myself, whose daily avocations run in a different groove. For my part, I shall deem my efforts amply rewarded, if my countrymen, to whom original researches are as yet a thing of the future, find in the life and doings of my author a living example of what patient inquiry after truth and diligent struggle after knowledge can achieve. But I caution them again against high hopes. To appreciate the man, one must compare his work with others produced under similar conditions. It will be unfair to expect anything new in the work which will be useful to those who have studied

European Science. Let me therefore briefly recount a few bright names from the annals of our ancient astronomy that the present work may be taken at its true worth.

Not to dive into the antiquity of Hindu astronomy, which is as old as the Vedas and regarding which abler men have measured swords, let me begin the story from the point where we tread on the firm ground of history. It begins with ***Aryabhatta** of Kusumapura* (Pataliputtra), the ***Andubarius*** of the Greeks, the *Arjabhar* of the Arabs, and the Indian founder of the theory of the earth's daily rotation. He was born in the Saka year 398 (A.D. 476) and wrote his famous work at the age of twenty-three. It was he in whose work we find, as far as our present knowledge goes *the first successful attempt to solve indeterminate equations of the first degree.* He enjoyed a wide reputation which can only be explained by supposing that he was an original observer and made improvements upon older astronomy.

Hindu astronomy was then passing through the state of childhood, and a few years later, we find ***Varaha mihira*** *of Avanti* (Ujjayini), adorning the court of Vikramaditya the Great, about whom many a tale of adventure and narrow escape from death has been recounted. Varaha's encyclopaedic knowledge made him famous. But he is remembered more as a compiler than as an original worker. His astronomical compilation, named *Pancasiddhantika* was written about the Saka year 427 (505 A.D.)

Next, the name of ***Brahmagupta,*** son of Jisnu, introduces an important chapter in the history of Sanskrit astronomy. He wrote his work, *Brahmasphuta - Siddhanta* in Saka 550 (628 A.D.) at the age of thirty, somewhere near

Rewa. He was a practical astronomer, and made several corrections in the older astronomy. Indeed, the form in which we find Hindu astronomy at the present day, dates from him. He was a *consummate algebraist,* from whom the Arabs got their knowledge of the science. *An indeterminate equation of the second degree, of which he gives a solution,* was a prize problem in Europe as late as the 17th century.

But the fame of ***Bhaskara*** born in the Saka year 1036 (1114 A.D.), near the Sahyadri (Western Ghats), threw all his predecessors into the shade. He is a glory to us, wonder among Europeans. His great work *Siddhanta - Siromani,* is one of the standard treatises of the present day. He appears to *have made use of the Differential Calculus.* *

With the death of Bhaskara, the living breath of mathematical science parted from India. Repeated invasions by a barbarous nation poured forth an abundance of calamities and in the troubled times the sacred muse of learning fled and hid herself among a herd of commentators in the Deccan. In the dark ages that followed, amidst the petty dissensions of a host of semi-independent States, we find intellectual effort at a stand-still; men were content to chew the cud of what their predecessors had thought and done. At least, one name of this period is worth mentioning. This is ***Ganesa*** of Nandigrama who wrote his *Graha laghava* in Saka 1442 (1520 A.D.), a work which has been employed as *an easy hand - book of astronomy* in some parts of the country. Arab influence and, latterly, the contact with Europeans did not benefit the science much. It was during the reign of ***Jayasimha*** of Jayapura so late as the 17th

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* See a brief account of Bhaskara by Pandita Bapudeva Sastri in Journal ASB of 1893.

century, that the Arabic ***Almagest*** and ***Euclid*** were translated into Sanskrit, and it was he at whose instance five observatories were built at various places in Northern India.

The long chain of astronomers was snapped asunder for a period of at least four hundred years. No doubt, there were astronomers, as there are now, and some of them may have for a time enjoyed a reputation, however local in character. But they have hardly left any permanent mark on the progress of the science.

Will it be estimating this work too highly if we regard Chandrasekhara as forming a link in the long chain? Be that as it may, it is a most gratifying thing that Chandrasekhara has not laboured in vain. His work has already exercised an influence upon Hindu astronomy, and hence upon Hindu society. I say, upon Hindu society, to which a correct knowledge of the ever-changing positions of the heavenly bodies is neither a matter for the inquisitive, nor one which may be safely let alone. For, Hindu life is nothing, if not a routine of religious practices, due observance of which necessitates a knowledge of the positions of the planets and the stars. Indeed, a correct almanac is an indispensable equipment of every Hindu household. All religious observances and rites are regulated by the almanac, and some of these rquire very accurate determinations. For instance, a Hindu must know the exact moment when a particular position ends and another begins.

It has, however, been observed that no two current almanacs agree in their computations. A fierce controversy is going on between the conservatives and the liberals in Hindu India about the correction of almanacs, and therefore

about the data of the Siddhantas. The orthodox of the Hindu community refuse to believe in the existence or errors that have crept into the figures of the old Siddhantas in course of time To use the foreign Nautical Almanac to regualte the religious observances is out of the question. Any correction, if necessary, must come from within, from a Hindu uninfluenced by foreign education. It is not for Europe, with all her brilliant scientific discoveries and wonderful inventions of labour-saving machinery, to take the place of the old Rishis, whose hallowed names are associated with every department of useful knowledge. Europe may be our guide in matters temporal, but must not dictate a word in matters spiritual. Materially, a Hindu is hardly a Hindu of old days, though spiritually, I believe, he is still the same.

The value of the *Siddhanta-darpana*, the work of an orthodox Hindu, showing errors in our current almanacs, cannot thus be over-rated. Here is a man who has practically tested the elements hitherto followed, and found reasons for correction.And he has authority for doing so from the honoured Rishis, who have given their sanction to the adoption of such corrections as may be necessary for the purpose of making calculation agree with observation.

The influece which Chandrasekhara's work has already exerted upon society is not inconsiderable. Some twenty-three years ago a meeting of learned Panditas and Hindu astronomers was called at Puri to select an almanac according to which the numerous daily rites of worship were to be conducted in the temple. The meeting decided in favour of the almanac computed after this work. One of Chandrasekhar's pupils has been computing an almanac every year, which is used not only at Puri, but throughout

the greater part of Orissa. Another pupil of his publishes a Bengali almanac, which has a by no means insignificant sale. Thus Chandrasekhara has already gained a foot-hold in Hindu Society and has inagurated silently but effectually an advance upon the current almanacs. At any rate, he has silenced all opponents, and has made question of correction possible in the near future.

To fully appreciate him, it is necessary to say a few words on his early life and education . Some four years ago, I first made his acquaintance, and from conversation with him on astronomical subjects, I was surprised to find him a man of genius and extraordinary merit. Since then I have looked into his work, ***Siddhanta-darpana***, written on palm leaves in Oriya character, the result of his life-long labour in the field of astronomical research. Two years ago he was honoured by Government with the title of Mahamahopadhyaya, a title hitherto enjoyed only by Brahmanas versed in Sanskrit lore. Chandrasekhara, however, is not a Brahmana but a Ksattriya by caste.

He was born in the Saka-Year 1757 (1835 A. D.) in the small village of Khandapara, some 50 or 60 miles west of Kataka, amidst the hills and jungles for which Western Orissa is famous . It is the chief town of the Raja of Khandapada - one of the tributary chiefs of Orissa. Chandrasekhara belongs to the Raj Family, the present Raja, Natabara Mardaraja, Bhramaravara Raya being a son of Chandrasekhara's eldest cousin ✡. The full name of the

✡ The relationship will be clear from the following :-

Nrisimha (Raja, Mardaraj Bhramaravara Ray)

Purusottama — Syamabandhu (Simha Samanta)

Krushna Chandra — Chandrasekhara

Natabara (Present Raja)

author is Chandrasekhara Simha Samanta Harichandana Mahapatra. Harichandana and Mahapatra are mere titles bestowed by the Raja of Puri, whose influence upon the destinies of the Rajas of Orissa is still as unbounded as was that of the Pope of Rome on the vassals of medieval Europe. He is styled Samanta as befits a member of the Raj family. In Orissa, however, he is best known by the familiar name of Pathani Santa (corrupted from Pathan and Samanta), a nickname given him by his parents on account of their first two children having died in infancy.

At an early age Chandrasekhara received instruction in Sanskrit. For some time he studied Sanskrit Grammar, Smritis and Puranas, logic and medicine, and read all the important Kavyas in the original. His education has thus been varied and many- sided. But it has stood him in much better stead than the modern elaborately arranged curriculum of the English schools, through which he would have been thrust, had he lived nearer a town.

At the age of ten, one of his uncles taught him a little of astrology. He showed the young Chandrasekhara some of the stars to satisfy his curiosity, so natural in young children and thus gradually initiated him into the mysteries of astrology. At this age, his extraordinary desire to test for himself the position of the stars as they changed night after night was predominant. The determination of *Lagnas* is a very frequent necessity in horoscopy; and the varying positions of the planets among the stars, without a knowledge of which astrological predictions could not be made, led him to watch their movements. This idle curiosity exhibited in star-gazing developed into the habit, of a really fruitful study of astronomy. There was, however, no

teacher who could instruct him in the science, and he was (and is still) quite ignorant of any language save Sanskrit and his mother-tongue Oriya. He found, however, a few Sanskrit *Siddhantas* in the family library, and applied himself diligently to master them with the help of commentaries.

At the age of fifteen, when he came to learn the meaning of *Lagna* and the rules for calculating ephemerides of planets, he was surprised to find that neither did the stars appear on the horizon at the right moment, nor could the planets be seeen in their right places. Again and again, he measured with a graduated rod the relative distances of the heavenly bodies in the vain hope of finding an agreement between calculation and observation, and again and again his hopes were dashed to the ground. Was it possible that the rules and the figures of the famous *Siddhantas* were not accurate enough, or was it possible that he had made errors in his daily observations ? Correct observation was the only test to settle the question. There were no mathematical instrument-makers to supply him with the requisite instruments The old *Siddhantas* give brief instructions for constructing them, and he had no other alternative than to make for himself, a few primitive instruments for measuring time and angular distance.

Some of my readers may be desirous of knowing something of his observatory. It was the clear, blue vault of the heavens that was his observatory; and its equipment consisted of an armillary sphere and a vertical wheel as substitutes for modern transit and altazimuth, and the time-honoured clepsydra took the place of the sidereal clock. Of course, the all-useful gnomon found a place in the observatory, and I am informed, he had also a self-revolving

instrument (स्वयंवहयन्त्रम्) made of the pericarps of the Bottle-Gourd (*Lagenaria Vulgaris*) with water and mercury. But it was more of the nature of a curiosity than of much practical use. The instrument of which he made constant use, was one devised by himself. This, which he is fond of calling his Manayantra (Measuring Instrument), may be properly called a tangent-staff. It consists of a thin rod of wood, twenty-four digits long, at one end of which is fixed another rod at right angles in the form of a **T**. The cross-piece is notched and also pierced with holes at distances equal to the tangents of the angles formed at the free extremity of the other rod. Of course, such a rude instrument did not admit of being so divided as to enable him to measure a degree with any accuracy.

But it is a real pleasure to see him handling his Manayantra with a precision marvellous to behold. Constant practice has given him such facility with it, that he would not care to have recourse to his other instruments although better suited for measurement of vertical angles. Indeed, in most cases, mere inspection is often sufficient to enable him to hit the angle to the nearest degree.

One instance of the perfection he has attained by practice came before us when I saw him for the first time. Some of my friends doubted his pretensions to practical astronomy, and were desirous of testing his knowledge. One evening when Mars and Venus were about 6^0 apart in the western sky, he was requested to show, if he could, with the help of any improvised instrument the actual distance between the planets. After a moment's pause, he made his *Manayantra* out of a stick 42 digits long, attaching a cross-

piece of $4^1/_2$ digits to one end. The trigonometrical functions of *sines* and *cosines* were all committed to his memory. The necessary calculations were mentally made, and the instrument was ready in a few minutes.

On this occasion, he saw a telescope for the first time. He had heard of its wonderful powers, but had no idea of its performances. He requested me to show him the planets through one. Unfortunately, I had with me then a telescope no bigger than a refractor of $3^1/_4$" diameter. This was adjusted for him with a power of 80. The keen delight with which he looked at the varied and picturesque appearance of the moon, absorbing him for some time can better be imagined than described. When the novelty of the aspect had abated a little, he wanted to know the magnifying power. He was told to find it out for himself, if he could. The question is itself puzzling and I did not expect any answer. But he startled me by saying that the instrument magnified about one hundred diameters. He had measured the enlarged image of the moon as seen through the telescope and had compared it with the apparent diameter well-known to him.

The planet Jupiter was next shown through the telescope. I should rather say that he directed the instrument to the planet and saw it himself. The apparent motion of the planet quickened by about a hundred times through the instrument, was followed by him for some time till he could see the belts and the satellites to his heart's content. It was at this moment that he gave vent to his bitter regret that he had not the advantage of such instruments in his younger days.

Next morning we had a talk about *tithis*. I said that the almanac-makers of Bengal would not believe in any variation in accepted duration of the *tithis* Hearing this, he was silent for a minute or two, as if he doubted the fact. Being pressed for his opinion, he quoted a line from his work, meaning that arguments can never defeat the results of direct observation.(प्रत्यक्षानुभवं न लुम्पति वचो युक्तिर्यतः ।)

He had read in a vernacular text-book that the sun sometimes exhibited dark spots on his radiant orb, and was anxious to see if it was really so. I asked him to accept the fact as true; but he said he would not believe it unless he saw spots with his own eyes. To this I retorted by asking if he had ever believed in the existence of the seven atmospheres of the *Siddhantas*. His reply was that the statement was to be taken at what it was worth, and he had no opinion of his own to give. The minimum sun-spot period had been passing; but a few that he saw made him reflect upon them a long while.

None can read his life without gaining a fresh insight into the marvellous thoroughness with which our ancestors devoted themselves to their studies, our university-men being only surface-deep in subjects more than one. The living breath of science has departed from India with the departure of men whom Chandrasekhara had made his ideal. He is an adherent of truth obtained by direct observation, and with all his respect for the ancients, would not hesitate to denounce a Sastric authority, if a proof to the contrary were obtained. Were he placed in a well-equipped observatory of modern days, I doubt not, he would enrich science with his assiduous labour and valuable observations.

Unaided and surrounded, as he was by practical difficulties, what patient labour he must have undergone in his early days to observe and work out practically the astronomical elements of the planets. What numberless observations must he have made to test every figure used in the *Siddhantas*, in order to see if it remained true or not. Night after night passed away in the all-absorbing business of star-measurement. An eclipse of the sun or of the moon was an event in his life never to be forgotten.

Thus it was that his early days passed. To the uninitiated, his was a frivolous work fit for children in want of better employment. Those who cared to understand his business failed to appreciate it. What, if the planets moved out of their path ? Besides, was it not the work of professional astrologers ? And was it not an unbecoming one in his position ? He began to be called by the people Raj-Jyotishi as a sort of nickname. The Raja of the State considered himself degraded by the profession of his uncle, and could never countenance his pursuits. Thus his relations with the Raja have become far from cordial, and the latter has been unable to appreciate the utility of his work.

At the age of twenty-three, Chandrasekhara began to note down systematically the results of his observations and three years later the idea of embodying them in a work flashed into his mind. By this time, his mastery over Sanskrit had become so complete that he could compose elegant verses in it impromptu. Indeed, the composition of his work had begun in his mind long before it was written on palm-leaf. In this way, between observation and measurement and composition his days were divided. He was incessantly engaged with his work for the full period of six years, and the first copy was not ready before he was thirty.

This constant strain upon his body which had never been strong began to undermine his system. He contracted a disease which has been his constant companion. Besides, the privations he had to bear, consequent upon his scrupulous adherence to the Sastric injunctions of strict vegetarianism, proved too much for his naturally weak system. Dyspepsia with its attendant colic has impaired his health. At times it becomes so painful that he is compelled to break off conversation and roll down on the ground till the attack is over. Full meals, frugal as they are, he has not enjoyed for the last thirty years, and has seldom permitted himself the indulgence of even half meals twice a day. The study of astronomy has been a passion with him, and any medicine you may prescribe for him, must neither contain any forbidden ingredient, nor what is more important, interfere with his daily work. Even in his present invalid state he would willingly sit up a whole night if it were for anything connected with his favourite subject. When he came here to receive the title of honour conferred upon him he could not be persuaded to stay a single day after the Durbar, as an eclipse of the Sun was to occur a few days later. And how could he stay away from his observatory, and allow such a momentous event to pass by unnoticed ?

His naive simplicity and unassuming manners have rather been a drawback than an advantage to him. The common people, who do not understand the difference between astrology and astronomy, pester him so much with questions on their destiny, that it is only his amiable disposition that makes him endure the constant infliction. Even those who might be expected to know better will not scruple to ply him with absurd questions and waste the

few moments left to him between the beginning of one series of daily devotions and the end of another.'

If he is a practical mathematician,no one is so unpractical in worldly matters as he is. Simple as a child,he depends upon his servants for his guidance. Neither is he well-off, in the sense of possessing a competency in life; and, related as he is to a Raja, he is unable to make both ends meet. A retinue of attendants hereditarily maintained in his family has to be supported in the usual manner. The small income of Rs.500 a year from a few small villages, and a quantity of food-grains from his tenants, are hardly sufficient in these days of high prices. Poverty has pinched him in his old age and has compelled him to incur a large debt.*

The general public does not care to know his incomings and outgoings, his privations and star-gazings. "What has he done after all ?" - asks the impatient critic. To him, I would say, is it not enough to find in this man a true lover of science who regardless of other people's unfavourable opinion of his work, their taunts and dissuasions, has devoted his whole life to the one pursuit of knowledge; who has shown the way to original research amidst difficulties serious enough to dishearten men in better circumstances; who has employed his time usefully, instead of frittering it away like the usual run of men of his rank, on a work which guides the daily routine of millions of his countrymen ?

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* For two years past, he has been obliged to compute an ephemeris for local publisher, who pays him the insignificant sum of Rs.300 for the immense labour required for the work.

I do not pretend to express any opinion on the literary merits of his work, but it appears to me that the metrical composition alone, apart from its value as a contribution to Hindu astronomy is such as to entitle him to a high place among the writers of Sanskrit verse of the present day. It contains, as he tells us at the end of the work, 2,500 *slokas* of various poetical metres. Of these 2,284 verses have been composed by him and the remaining 216 quoted from the old *Siddhantas*. Of the latter, the *Surya Siddhanta* and the *Siddhanta Siromani* have been very largely drawn upon. Indeed, as Bhaskara had Brahmagupta for his guide, when writing his *Siromani*, Chandrasekhara has, in the main, followed in the footsteps of Bhaskara.

But Chandrasekhara has not been a blind follower of his master. The elements of the planets, given by Bhaskara, have not been accepted by his disciple, and for the simple reason, that they are not correct for the present day. Bhaskara's elements are not accurate, though there is no reason for doubting the accuracy of his observations. The fact is, he had to depend upon his predecessors-probably Brahmagupta was his main guide-for the positions of the planets and was thus led to erroneous results.

Chandrasekhara had the advantage of Bhaskara's observations. The latter has of course, nowhere recorded his observations. But given his date and his elements, it is easy to find the positions of the planets as he must have observed them. For, the elements, if employed to calculate the positions of the planets after a long interval, may lead us to wrong results ; but, if employed for places nearer his time, will be in accordance with his observations. Thus, furnished with one set of positions at a given date, Chandrasekhara himself supplied the other set required and

the result obtained is what Chandrasekhara has given us in the present work. For easy reference, the sidereal periods as he ascertained them, are given below side by side with those of European astronomy, the *Surya-Siddhanta* and the *Siddhanta Siromani* . It is not my object to criticise how far the constants employed in these two *Siddhantas* were true when they were observed, though it will be clear from the comparison that they are certainly erroneous for the present time. It is easy to follow when someone has led the way; but it needed the art of a rural Pandit, guiltless of western " fire" to prove their incorrectness and to pave the way for further progress in this department .

SIDEREAL PERIODS IN MEAN SOLAR DAYS

European Astronomy Planets	Surya Siddhanta	Siddhanta-Siromoni	Siddhanta-Darpana
(1)	(2)+Difference	(3) +Difference	(4)+Difference
Sun ...365.25637	365.25875+.00238	365.25843 +.00206	365.25875+.00238
Moon......27.32166	27.32167+.00001	27.32114-00052H	27.32167 +.00001
Mars 686.9794	686.9975 +.0181	686.9979 +.0185	686.9857 +.0063
Mercury .. 87.9692	87-9585H.0107	87.9699 +.0007	87.9701 + .0009
Jupiter 4332.5848	4332.3206H.2642	4332.2408H.3440	4333.6278 +.0430
Venus 224.7007	224.6985H.0022	224.9679H.0028	224.7023 +.0016
Saturn 10759.2197	10765.7730 +6.5533	10765.8152 +6.5955	10759.7605+.5408

It will be seen from the above that Chandrasekhara has practically assumed the sidereal periods of the sun and the moon, as given in the *Surya-Siddhanta* but has materially advanced upon it as regards the periods of the other planets. Having regard to the comparatively slow motion of Jupiter

and of Saturn, and the nature of the instruments used, it would have been a surprise if closer approximation to their true periods were made.

Let us now compare the main inclinations of the orbits of the planets to the ecliptic.

	Eng. Astronomy			Surya S.		Siromani		Darpana	
Mercury*	7°	0'	8"	5°	25'	6°	55'	7°	02'
Venus*	3°	23	35	2	46	3	06	3	23
Mars	1	51	02	1	30	1	50	1	51
Jupiter	1	18	41	1	0°	1	16	1	18
Saturn	2	29	40	2	0°	2	40	2	29
Moon	5	8	48	4	30	4	30	5	09
Obliquity of the Ecliptic		23	27	24	0°	24	0	23	30

On account of the difference in the planetary theories and in the method of calculation between modern astronomy and our *Siddhantas*, the eccentricities of the planetary orbits cannot be compared with advantage. But as they make no difference in the case of the sun and the moon, their greatest equations are given here for comparison.

The inclination given in the *Siddhantas* is reduced to the geocentric system. The general reader may be reminded that the inclinations are all subject to variation and that the old *Siddhanta* values were not so far wide of the truth, as they appear from the table.

	English Astronomy	Surya-Siddhanta*	Siddhanta Darpana
Sun	1° 55′ 19″	2° 10′ 31″	1° 55′ 33″
Moon.....	6 03 41	5 02 46	5 01 10

It will be needless to compare the rates of motion of the nodes and apsides. It is possible for modern European astronomy, with instruments enabling it with ease to measure the three thousand and six hundredth part of a degree, and with its engines of higher mathematics to handle intricate problems, unheard-of before, to deduce the elements of orbits from a very few observations made at no distant dates. But it requires the lapse of years- nay centuries- to do the same with primitive instruments and equally primitive mathematics. The motions of the nodes and apsides are so slow that Bhaskara despaired of ever measuring them. Chandrasekhara was equally in despair in these cases. But as the positions of the Moon's nodes and perigee are oftener required, and their motions comparatively rapid, I quote their **sidereal period in mean solar days.**

	Eng. Ast.	Suryas	Siromani	Darpana
Node	6798.279	6794.395	6792.254	6792.644
Perigee	3232.575	3232.094	3232.734	3232.657

The reader will notice that Chandrasekahra has devised a correction to be applied to the *mandocca* of the planets, Mercury, Mars and Saturn. He has called it *parocca* and the greatest amounts are 11° 20′, 7° 30′ and 5° for the three planets respectively (V.76)

* According to *Siromani*, the sun's equation is the same as is shown under *Surya-Siddhanta* and the moon's equation is slightly less.

It is however, in computing the Moon's place that Chandrasekhara has discovered some original corrections,- original in the sense of their having been unknown to the ancient astronomers of our country. It is curious to note that they failed to discover the perturbation, known as Evection which is said to have been detected by Hipparchus about 150 years B.C. It is an irregularity which may put the moon forward or backward over a degree. Pandit Sudhakara Dwivedi informs us in his excellent manual, called *Ganaka-Tarangini* that Munjala(A.D. 933) had something like "evection' in his *karana* named *Laghumanasa*. He appears to have been the oldest Hindu astronomer who detected the irregularity, though curiously enough, his successors including Bhaskara left it unnoticed.

The next large irregularity of the moon, called " *variation*," has a period of one month, and a maximum of 39'31" This inequality does not affect the time of an eclipse, and the fact sufficiently explains its absence in Sanskrit *Siddhantas*.* It is said to have been detected by an Arabian astronomer, Aboul Wefa about the year 975 A.D., and re-discovered by Tycho Brahe in the 16th century. The last large inequality of the moon's place is called "*annual equation*," and has the maximum amount of. 11' 9". This was also discovered by Tycho Brahe.

It is singular that Chandrasekhara is the only Indian astronomer who has detected all the three important irregularities of the Moon. As has been said before, he did

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* From Dwivedi's *Ganaka-tarangini*, it appears that Nityananda in 1639 A.D. used a correction called *Paksika*. But it is not clear from the name alone, if it had any connection with "variation".

not know English and had no means of knowing the existence of the irregularities from any foreign source; and the methods of applying the corrections together with discrepancies between his values and those of Europe leave no doubt in our mind that he must be credited with their discovery. He has named the inequalities, *Tungantara, Paksika* and *Digamsa,* with the maximum amounts of 2^0 40′ , 38′ 12" and 12′ respectively (S.D.VI. 7).

For those who may be inclined to compare his corrections, his method of applying them is briefly described here. After the equation of centre (maximum amount 5^0 1′ 10") has been applied to the mean moon, call the result 1st Moon M_1 Then add to, or subtract from it, according as the anomaly happens to be within the first six or the second six signs,

$$160' \times \frac{\text{Sin}[A- (O \pm 3)]}{R} \times \frac{\text{Sin}(M_1 -O)}{R} \times \frac{\text{1st moon motion}}{\text{mean motion}}$$

where A stands for the Moon's apogee, and O for the true Sun, the two signs ($\pm$) are to be taken in the case of the light and dark halves of each lunar month respectively. The result obtained is called the 2nd Moon ,M_2.

To apply the *Paksika* correction, take M_2-$^O/_3$=a+$^b/_3$ (say). Subtract $^b/_3$ from 3 (Signs) and take the less of two quantities, *a* and (3-$^b/_3$) and say, it is *Y*. Then, sin $^{2y}/_{90}$is the correction required. It should be noted that the denominator (90) is not constant, but can be obtained. The correction is to be added to, or subtracted from the 2nd moon, as the latter lies within the first or the second quadrature. Call the Moon thus corrected, the third Moon, M_3.

Now, take 1/10 of the Sun's equation and multiply by the first Moon's motion, dividing by its mean motion. Add the result to the 3rd Moon, when the Sun's equation is subtractive, and subtract from it when the Sun's equation is additive.After this, the other corrections (such as *Bhujantara*), common to all the planets, are to be applied before the Moon's place becomes apparent.*

On a cursory view, the amount of *Tungantara* inequality appears double of that of *evection*. But if we take the Moon's greatest equation of centre into account, the apparent discrepancy vanishes. For, the amount of the greatest equation of the Moon is 6° 18′ , and the maximum evection 1° 20′ making the total of 7° 38′. Chandrasekhara has 5° 1′ as the greatest equation and 2° 40′ as the greatest *Tungantara*, making the total of 7° 41′. The other inequalities discovered by Chandrasekhara are about the same as those in use in English astronomy.

The astronomical constants adopted by our Indian astronomers open up a large field for enquiry. It is not my purpose to discuss their bearings upon the antiquity of Indian astronomy. But I cannot but remark that it is often reiterated in season and out of season than substantiated, that the Indian astronomers borrowed largely from Greek astronomy. As far as I am aware, this assertion is based upon(1) the identity of certain Sanskrit and Greek astronomical terms, (2) the fact of **Garga** praising the **Yavanas** for their proficiency in astronomy, and (3) the presence in Sanskrit of certain astronomical treatises

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* It should be noted here that the last-named inequality (*Digamsa*) is also applied to the moon's node in the above mentioned manner (S.D.VIII.33).

admittedly of foreign origin . This is not the place to discuss the subject thoroughly. But as far as my knowledge goes, these arguments, when weighed against others, are not at all convincing.

The presence of Greek terms in Sanskrit is certainly a strong presumption in favour of the theory. But when the uses of the terms are taken into consideration, it is found that with the possible exception of the word *'kendra'** meaning " anomaly, all the rest properly belong to astrology. Of course, when once the terms had been introduced into Sanskrit , our astronomers did not hesitate to use them freely in astronomy, side by side with pure Sanskrit terms.

The passage where Garga extolled the Yavanas does not occur in an astronomical work but in a *Samhita* which was rather a work on astrology than astronomy. Nor can we logically infer from the passage that the Yavanas were proficient in astronomy rather than in astrology, or that the Hindus borrowed the knowledge from them. The name Yavanacarya occurs only in connection with *Samhita* . Next, the presence of Romaka** and Paulisa *Siddhantas* among others of purely Indian origin proves nothing beyond the bare fact of their presence, and I do not see how it can be taken to imply that the Hindus had not obtained the constants of their *Siddhantas* by independent observation . On the contrary, the fact of their retaining the foreign name (at least the name *Romaka*), shows that the foreign *Siddhantas* were distinct from what were Indian, and there is no proof that the *Romaka* or any other foreign *Siddhanta*

* See, however, Bhaskara's derivation of the word in his *'Siromani'*.

** The *Romaka-Siddhanta* of Varahamihira is in no way superior to his *Saura-Siddhanta*, as was remarked by himself.

was ever in use in this country, superseding the purely Indian production. To give an analogy, a Sanskrit translation of the British Pharmacopaeia will no more prove the absence of Charaka than an English translation of the latter will prove the absence of the former. All that we can logically infer is that there was intimate intercourse between the Hindus and the Yavanas, a fact otherwise known from political history. The Hindus may have been indirectly influenced by the teachings of the Yavanas. But it must be admitted that the Yavanas may have been also influenced by their presence among the Hindus.

We can safely go so far, omitting all sorts of possibilities and vague conjectures. Having regard to our ignorance of the state of astronomy and its gradual development in India anterior to ***Aryabhatta***, and our equal ignorance of the source of the knowledge credited to ***Hipparchus***, it is hazardous to speak of the indebtedness of the one nation to the other. If the Hindus learnt the science of astronomy from the Yavanas how is it that the constants of Sanskrit astronomy are so different from those of Ptolemy ? How is it that the early Hindu writers were unacquainted with such useful as well as remarkable facts as the precession of the equinoxes, or the evection inequality of the Moon ? On the contrary, the constants ought to have been identical, not only because they are believed to have a common origin, but also because they represent facts, as true for India as for Egypt or Greece. When one learns a science from another it is natural to expect to find him copying not only the theory but also the practice, right or wrong. Dr. Thibaut repeats the suggestion made by Biot, that the early Hindus learnt their astronomical theories probably from Greek astrologers and the Doctor

adds, also from almanac-makers, whose knowledge was as limited as that of their proto-types in the present day.* This is certainly an ingenious hypothesis; but as has been already remarked, having regard to our ignorance respecting the growth and development of the science in India as well as in Egypt, we cannot but regard the hypothesis as not proven I am inclined to believe that our knowledge of the source of Hindu astronomy has not advanced beyond the point where Colebrooke found it. All that can be safely asserted is what the illustrious oriental scholar said, that "the Hindus have certainly received and welcomed communications *from other nations on topics of astrology*" and we add, that their indebtedness to Greece for the knowledge of scientific astronomy is still an open question.**

But this is a digression. We have said that Chandrasekhara had made a real advance upon existing Hindu astronomy. But the best test of a theory lies in facts. For the reason given below, it is not easy, however, to satisfy oneself whether his ephemeris is correct, and how much confidence may be placed in it. For rough comparison, the places of the planets computed by him are shown below, together with their places, first according to the British Nautical almanac, and next according to a widely circulated Bengali almanac said to have been computed after the *Surya-Siddhanta*. The correction for precession in the places given in the Bengali almanac has

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* See Introduction of *Panca-Siddhantika* by Dr. Thibaut and M.M. Sudhakara Dwivedi.

** It is much to be desired that some competent scholar would collect the argument for and against the theory of indebtedness, and let us know how far, and in what direction, great influence on Hindu astronomy extended.

been made by adding 20° 54′ to them in accordance with the almanac. Besides these, I append ephemeris for two other days from the Nautical Almanac and the *Siddhanta-Darpana*.

For various reasons, neither Chandrasekhara's, nor for that matter - any other Hindu almanac, can coincide with the Nautical Almanac. Neglecting minor corrections unknown in our almanacs, there is the determination of the exact amount of precession, without which no comparison is possible with European almanacs. To avoid it, the relative distances of the planets may be taken. It will be seen that while the Bengali almanac may be in error by as much as 4°, the error in the ephemeris by the *Siddhanta-Darpana* is limited to half-a-degree. The reader will, however, remember that a Hindu astronomer depends upon unaided vision and is satisfied if the longitudes are correct to half a degree. Accepting this as our standard, the ephemerides by the *Siddhanta-Darpana* compare favourably with those of the Nautical Almanac, while the greater discrepancies in the Bengali almanac conclusively prove how urgent has been the question of the revision of our existing almanacs in the light of observations now made.

But before any reformation is attempted, an exact determination of the amount of precession becomes a question of paramount importance. The reader is aware that in the Hindu system, the longitudes of celestial bodies are measured from a fixed point, say a star, in the ecliptic, instead of from the movable vernal equinox as is the practice in Europe. The question has therefore the same bearing upon our calculations, as the position of the so

called First Point of Aries upon those of the Nautical almanac.

LONGITUDES OF PLANETS ON THE 31ST JANUARY 1894(KATAK, 6 P.M.)

	Nautical Almanac.	Siddhanta-Darpana From Fixed Aries.	Siddhanta-Darpana From Vernal Equinox	Bengali Almanac From Fixed Aries	Bengali Almanac From Vernal Equinox	Dec. by N.A.	Dec. by S.D.
Sun	10ˢ 11° 54	9ˢ 19° 31	10ˢ 11° 56	9ˢ 19° 40	10ˢ 10° 34	17° 14′ S	17° 15′ S
Moon	4 4 26	3 12 16	4 4 41	3 12 1	4 2 55	24 1 N	24 15 N
Mars	0 22 48	0 0 7	0 22 23	11 29 43	0 20 37	9 14 S	9 7 S
Mercury	10 0 33	9 8 23	10 0 58	9 12 16	10 3 10	21 45 S	21 15 S
Jupiter	0 19 27	11 26 43	0 19 8	11 27 6	0 18 0	6 32 N	6 50 N
Venus	9 19 19	8 26 48	9 19 12	8 27 46	9 18 40	22 7 S	22 1 S
Saturn	6 12 43	6 20 38	6 13 3	5 22 14	6 13 8	2 41 S	3 0 S

20th February 1894 (Katak, 6 P.M.) 1st March 1894 (Kataka, 6 P.M.)

	N.A.	S.D.	N.A.,	S.D.
Sun	11ˢ 2° 8′	11ˢ 2° 9′	11ˢ 11° 10′	11ˢ 11° 11′
Moon	0 21 40	0 21 46	4 27 7	4 27 4
Mars	1 6 5	1 5 30	1 12 3	1 11 27
Mercury	11 5 14	11 4 57	11 22 14	11 22 39
Jupiter	0 22 58	0 22 34	0 24 46	0 24 21
Venus	10 14 16	10 12 42	10 25 28	10 25 25
Saturn	6 12 1	6 12 23	6 11 13	6 11 56

Unfortunately, all attempts to solve the question have been practically fruitless. The reader will hence understand

the chaos into which our almanacs have sunk. The gravity of the situation, and the difficulty of escaping from it, demand a fuller discussion than our space would permit. But then this alone can give us an opportunity of ascertaining Chandrasekhara's success in this direction.

Premising, then, that we measure longitudes of planets from a fixed point in the ecliptic, the question resolves itself into a determination of the point. In other words, what is that point, or what is its longitude from the vernal equinoctial point ? Whatever and wherever that point may be, it is the starting point of our zodiac, and its longitude is known as *ayanamsa*, which literally means the amount of solstices. For, we don't speak of the precession of the equinoxes as often as we do of the precession of the solstices. Hence, the *ayana-calanam* of Sanskrit astronomy is equivalent to the precession of the equinoxes. To avoid ambiguity we shall use the term *ayanamsa* rather than the amount of precession.

The exact amount of the *ayanamsa* may be apparently determined in different ways. (1st) The *Siddhantas* furnish a rule for computing it, which is in principle the same as the method of finding the longitude of a star at any given date by applying the amount of precession to its longitude at some other date. (2nd). Defining the initial point with the help of other data, such as the recorded longitudes of stars, its present longitude from the equinoctial point may be ascertained. (3rd) Knowing the exact year when the initial point was fixed, its present longitude (*ayanamsa*) may be calculated from the known rate of precession. But it so happens that the results obtained by these three methods do not agree.

To begin with the first method, it will be seen that the different *Siddhantas* do not agree either in the nature of precessional movement, or in its annual rate. According to some, the equinoxes have an oscillatory motion, turning to the right and to the left of the initial point within certain limits and extending over a large interval of time; while others maintain their continuous motion backwards. Colebrooke compared the views of the libration and revolution theorists, and gave the rate of precession according to each. They are as follows :-

Libration Theory		**Annual Rate**
Surya-Siddhanta	.....	54"
Soma*	....	54"
Sakalya	....	54"
Laghu-Vasistha	....	54
Parasara Siddhanta	.....	52".35
Aryasta Satika (quoted by Munisvara)	.....	46".25
Revolution Theory		**Annual Rate**
Munjala (quoted by Bhaskara**)	....	59".9
Bhasvati	.....	60"
Grahalaghava	.....	60"

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* Ranganatha,in his commentary to *Surya-Siddhanta*,quotes *Soma-Siddhanta* in support of the reading. त्रिंशत्कृत्ये युगे भानाम्

** Bhaskara did not believe in the libration theory. For, as has been shown by Chandrasekhara (VI.100), he has directed us always to add the *ayanamsa* and never to substract it.

The derangement of the equinox from the initial point is 27^{0} on either side according to the *Surya-Siddhanta*, and this limit was probably accepted by other libration theorists. *Aryasta-Satika*, however, gives the limit of 24^{0} instead of 27^{0} (Colebroke).

We are not concerned here with the theories or the limits of libration. *Surya-Siddhanta* and the works based upon it, are now almost universally adopted throughout India for computing an almanac, though in some places *Grahalaghava* occupies the field. Now, from the first , we find the *ayanamsa* for the first day of Saka 1816* (13th April 1894) was 20^{0} 55′, and from the second, 22^{0} 50′ for the same day. These amounts represent the minimum and maximum *ayanamsa* obtained from *Siddhanta* rules.

Both the *Surya-Siddhanta* and *Siddhanta-Siromani*, the standard *Siddhantas* at present in use, give a rule to test the amount of *ayanamsa* by observation. It consists in subtracting from 12 signs the longitude of the Sun computed after the *Siddhantas* for the moment when the Sun crosses the vernal equinoctial point. Thus on the 13th April 1894, the Sun's longitude for Greenwich mean noon was 23^{0} 32′ 7″, while an almanac gives us 1^{0} 21′ 25″ as the Sun's longitude for the same instant, making the *ayanamsa* 22^{0} 10′ 37″. It will be seen therefore that notwithstanding the higher precessional rate of the *Surya-Siddhanta*, the calculated amount becomes less than the actual by nearly, 1^{0} 16′ , while *Grahalaghava* makes it greater by about 39′.

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* In common parlance, we speak of the year being Saka 1816, though in reality we ought to say the first day of Saka 1817. The facts herein discussed were collected some time ago, and as it is immaterial which year is taken for illustration, they are not altered to suit the current year.

To come to the second method, viz. to find the true longitude of the initial point as defined by stars. All the modern *Siddhantas* agree in the statement that the longitudes of all heavenly bodies are to be measured from the Star Revati situated on the ecliptic. The star has been identified with ζPiscium. Now, this is a star of the fifth magnitude and is barely visible to the naked eye. The question is, why was this particular star out of the many situated on the ecliptic,-- some of which are larger,-- chosen for marking the beginning of the the zodiac ? The answer has been -- and there is no doubt about the accuracy of the answer - that the vernal equinox happened near the star when the present system of astronomical measurement came into vogue.

So far it is plain sailing. For, we can easily find the longitude of the star from the vernal equinoctial point and at once get the required *ayanamsa*. From the Right Ascension and Declination of the star,ζPiscium, on the 13th April, 1894, we get 18^0 23′ 49″ as its longitude*. This is however, less than the amount obtained above. It is clear therefore that either the star Revati is not ζPiscium, or it did not mark the initial point. No doubt exists about the identity of the star, neither can we suppose all the *Siddhantas* false in their assertion.

The latitudes and longitudes of thirty-four other stars are given in the *Surya-Siddhanta*. They were not measured in the usual way. But from the express instructions as to the method of measurement adopted, we understand that the so-called longitudes, Dhruvas, are the longitudes

* The modern *Surya Siddhanta* gives $359^0$50 as the longitude of the star Revati. This would make the present *ayanamsa* greater by 10′ only.

of the Right Ascensions of the stars supposing them to be on the eclipitc, and that the latitudes (*Viksepas*) are the distances, north or south, of the stars from the ecliptic, measured along the declination circles passing through the stars. Now, taking only the 27 stars of the zodiac, and comparing their reduced Dhruvas with their present longitudes we find ourselves confronted with a curious result.* The difference between the recorded and the present longitudes is not the same for every star. Indeed, it varies from about 18^0 to 24^0.

Omitting Visakha, of which I am not certain, the mean difference of the longitudes of the stars of the first half of the zodiac, i.e. from Asvini to Chitra, is 21^0 while that of the stars of the second half amounts to 19^0 only. So, while the mean precession for all is about 20^0, that for Asvini (*a Arietes*) and Uttara-bhadrapada (*a Andromeda*), the two stars on either side of Revati, is about 24° each. The question becomes more perplexing when we remember that Bhaskara, who certainly made a few corrections, has given in most cases the same longitudes as we have in the current *Surya-Siddhanta*.

Our identification of some of the stars may be doubtful. ** But, taking all the star-longitudes into consideration, we are forced to admit that somehow or other there were errors of observation. Possibly, these errors were partly due to the rude means of observation, increasing the

* I understand that Prof. Whitney has discussed the point and regret that I have no access to his edition of the *Surya-Siddhanta* at present.

** Thus, if Asvini be identified with β Arietes and Uttara bhadrapada γ Pegasi, the amount of Precession deduced from them becomes nearly equal and agrees with that obtained from Magha.

errors with the increase of the zenith distace of the stars, and partly to azimuth errors. One or all of the explanations must be accepted as true, as we cannot suppose that any one having the slightest pretension to practical astronomy, however rough the instrument might be, could make such gross errrors in the simple measurements required. To take the mean of the star-longitudes for a solution of our problem is therefore a wrong procedure, in as much as, we are entirely in the dark as to the weight to be attached to the determinations. We shall, however, make use of them in another way later on.

We now proceed to consider the third method, which consists in analysing the dates in which there was no *ayanamsa*.For this purpose, we require not only the dates but also the rates of precession assigned by the astronomers. We have already seen the various rates assigned by them. As the *Surya-Siddhanta*'s rate of 54 seconds per year is a close approximation to the rate known at present, let us take this first for consideration.

Apparently, the rate of 54 seconds is higher by nearly 4 seconds than the actual. I say apparently, for the rate makes the *ayanamsa* less, instead of increasing it in the proportion of about 50 to 54. It must be therefore really lower than the true rate. To explain the anomaly we have to consider the *Siddhanta* year. The length of the sidereal year— the year used by us instead of the tropical year in use in Europe-- is 365.25875 mean solar days according to the *Surya-Siddhanta,* and is thus greater than the true length by 0.00238 days. Now, taking the Sun's daily motion at 59'8", we find that during the excess the Sun moves to the east through a distance of 8".44 nearly. But the equinoctial

point moves to the west. It is therefore clear that the precessional rate assigned by the *Surya-Siddhanta* is practically 54"-- 8" ·44 or 45" 56 per year. It is for this reason that the *ayanamsa*, calculated from the *Siddhanta*'s apparently higher rate, becomes less than the amount observed. Hence if we accept the *Siddhanta*'s length of the year, we would make the annual precessional rate 50" ·24+ 8" ·44 or 58" ·68. It is remarkable that the rate of 45"·56 per year is almost equal to the precessional rate in Right Ascension. Whether the *Siddhanta* writer meant the rate to be what we find, I cannot say, though there are certain reasons, favourable to our conjecture.

The point may be illustrated by taking other *Siddhantas*. Bhaskara's year consists of 365·258·43 days, and is therefore longer by 0·00206 days. Hence, accepting Bhaskara's year, we should have 50"·24 +7"·31 or 57"·55 as the precessional rate. Bhaskara doesn't state in his *Siromani* any rate deduced by him, but evidently supports Munjala's rate of 59"·9. Moreover,his adoption of the rate of 60" a year in his *Karana-Kutuhala* leaves no doubt in our mind as to the rate he used.

Similarly, Ganesha, author of *Grahalaghava*, makes the year of 365·25856 mean solar days, which is thus longer by 0·00219 days. He ought to have therefore made the precessional rate 50"·24 + 7"·86 or 58"·10 instead of 60" as he has done.

Chandrasekhara accepts the length of the year of the *Surya-Siddhanta*, and gives 57"·615 as the precessional rate (S.D. VI.75). This is just less than the rate we have assumed above by 58"·68 — 57"·62 or 1"·06. I was surprised to find

this close approximation, and could not but ask him the data from which he derived the rate. In reply, he said that finding the *Surya-Siddhanta* and the *Siromani* make the *ayanamsa* either shorter or longer than that observed, he was for some time in a fix about the rate to be folllowed. Fortunately, while he was studying *Jataka-karma-Paddhati* with the help of the commentary called *Jatakalankara* written by Suryadeva some 800 years ago, he accidentally found a passage in which the commentator recorded the *ayanamsa* as it was observed by him on a particular day of a particular year. This find itself is not less valuable than Chandrasekhara's rate. He gives however, 22°.26′ as the *ayanamsa* for the year we have taken for discussion.

Munjala appears to be the earliest writer who has given the date of the year of no *ayanamsa*, as well as the rate of precession observed by him. He wrote his work in Saka 854*, and the precessional rate assigned is 59".9 in a year.We also learn from Dwivedi's *Ganaka-tarangini* that according to Munjala, Saka 434 was without *ayanamsa*. Now from 434 to 854 Saka, there were 420 years, during which at the rate of 59"·9 per year, the *ayanamsa* had amounted to 6° 59′ 18". However erroneous the rate given by Munjala may be , it will not be wrong if we take 6°.59′ 18" (Say 7°), as the *ayanamsa* in Saka 854. We know, however, that the rate of precession could not have been greater than 58"·68 per year. Accordingly, the *ayanamsa*

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* The date 584 given in the *Ganaka - tarangini* seems to be a misprint, though it occurs throughout the short notice of Munjala, excepting in the passage where Pandit Dwivedi quotes कृतेष्विभमिते शाके from Munjala making the date 854 Saka, adopted above.

obtained above carries us back through 429 years from Saka 854, the date of Munjala's work. In other words, we find that according to Munjala's data, Saka 425 was the year of no *ayanamsa* at the latest. From the *ayanamsa* obtained from Munjala and that observed in Saka 1816, we note that the rate of precession amounts to 56"·8 in a year.

The next work we take is *Bhasvati* by Satananda, which is still regarded as an authority for the calculation of eclipses. He wrote his work in Saka 1021, and according to him the rate of precession is 60" per year.We also know that he regarded the Saka year 450 as the year without *ayanamsa*. Now calculating the amount of *ayanamsa* in Saka 1021 in the above manner, we find that it was 9^0 31′ in that year . From this, calculating backwards at 58"·68 a year, we come to Saka 437 as the year of no *ayanamsa*. We also note that the rate of precession deduced from the *ayanamsa* in 1021, amounts to 57".295 per year.

In his *Karana-Kutuhala*, Bhaskara has roughly given 11^0 as *ayanamsa* about Saka 1105. From this at the rate of 60" in a year, the rate assumed by him, we are taken back to Saka 555, and at the rate of 57"·55 which we have found before, to Saka 423. We also note that adopting his observation, the rate amounts to 56"·624 per year.

To take another example, we mention Ganesha who wrote his *Grahalaghava* in Saka 1442. According to him the rate of precession is 60" in a year, and Saka 444 was without *ayanamsa*. These premises lead us to infer that *ayanamsa* amounted to 16^0 38′ in Saka 1442, which at the rate of 58"·1 carries us back to Saka 412, a date which is the earliest of all that we have hitherto obtained. But, considering that the amount of *ayanamsa* deduced,

compared to the present amount, makes the rate as low as 53"·4, we are led to infer that his data were wrong. It is to be observed , however , that the rate of 58"·68 if adopted makes Saka 422 as the year without *ayanamsa**.

We may almost guess the data from which Ganesha derived his rate. It is likely he accepted 11° as the amount of *ayanamsa* in 1105, as recorded by Bhaskara. From this he might have obtained the Saka year 444 as the starting year, and also the rate of 60 seconds a year, making the amount 16° 37′ in Saka 1442.

It remains to notice the date 421 Saka given by some minor authors. This is obviously based upon the *Surya-Siddhanta*'s rule, with its annual rate of 54", making 20° 55′ as the amount of present *ayanamsa*.

Chandrasekhara has not recorded the data which furnished him the rate. Knowing, however, his *ayanamsa* and rate, and calculating backwards, we arrive at Saka 415.

So far we have obtained the following figures :

Munjala	......	425 Saka	56"·828 per year
Satananda	......	437 Saka	57·295 per year
Bhaskara	.....	423 Saka	56·624 per year
Chandrasekhara	.....	*415 Saka*	*57·615 per year*
Mean	.....	425 Saka	57"·09 per year

* An error in observing *ayanamsa* is not uncommon. One instance of it is furnished by Mahadev, who recorded 13" 45′ as the amount of *ayanamsa* in Saka 1238 (Dvivedi's G.T), thus making the rate since then 52"5′ in a year.

Having regard to the nature of the data we cannot expect a closer approximation than that shown above. We may therefore fairly take the mean of the dates, as well as the rates. On account of obvious inaccuracy in the data of Ganesha, the date and rate obtained from him cannot be rightly included. Neither will his date, if corrected, increase the weight to be attached to the mean to be calculated from the above figures. We might, however, include the data 421 Saka given by certain writers. Indeed, it will be seen that dates of the starting year are of two classes; one somewhere near 450 Saka, and the other, 421 Saka. But the dates of the former class may be reduced to those of the latter class. It will be further observed that Munjala, the earliest writer of the set, makes the closest approximation to the mean. Satananda seems to have committed an error seeing that he assigns Saka 450 as the starting year. Madhava Misra, a commentator of his, makes the same remark and suggests that the Saka year 421 ought to be taken in calculation.*

From what has been described above, the Saka year 421 or 427 appears to mark the beginning of the fixed zodiac. It is difficult to prefer one to the other. The Saka year 421 is equivalent to the year 3600 of the Kali-yuga, and the fact of its being so, goes in its favour. Besides, it is the year in which Aryabhatta composed his work, a work which enjoyed a wide reputation,. Lalla, whose

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* The copy from which the remarks are made, was printed in Benares Samvat 1942. It is full of mistakes, but the sense is clear. It is curious to note that Satananda, while basing his work on the *Surya Siddhanta,* gives a higher rate than what is given by the latter. Madhava Misra tries to justify this rate by altering the rule

''त्रिंशत्कृत्यो भानाम् to विंशत्कृत्वा युगे (कलियुगे) भानाम्'' ।

Tantra Bhaskara condescended to criticise, adopted the year 421 Saka, and the writer of modern *Surya-Siddhanta* evidently held the same view while writing the *ayanamsa* rule.

On the other hand, the great popularity of Varaha-mihira leads us to suppose that the present system of the zodiac had its beginning in Saka 427, and I believe all the anomalies noticed before, may be better explained by accepting the year. We have an authority for our view in the *Pancasiddhantika* itself. The often-quoted verse in which Varaha- mihira distinctly mentions the fact that in his time the summer solstice took place at the beginning of Cancer is a complete answer to the question we have been discussing.

Dr. Thibaut, the learned editor of the *Panchasidhantika*, however, finds difficulty in accepting Saka 427, as the date of the composition of the work. As far as I can gather from his introduction to the work, his main objection lies in a statement of Amraja, quoted by Bhau-Daji, that " Varaha- mihira Acharya went to heaven in the 509th year of the Saka Kala, i.e. A.D 587 ". For, if Varaha be supposed to have written the work in Saka 427, he must have lived to the good old age of eighty-two years after the composition; and supposing him to have written it at the age of twenty years, he must have seen 102 summers.

Seeing that Varaha lived long enough to write a very large number of works, there is nothing in the statement intrinsically impossible. On the other hand, if the Saka year were not the epoch of his *Karana*, he defeated his own purpose. Indeed, the idea of a *Karana*-writer using a

date borrowed from some older *Siddhanta*, as has been supposed in this case, and thus representing a time other than that for which the work is written,is to say the least, self-contradictory. Then again, as has been pointed out by Pandit Dwivedi, there is absolutely no proof of the validity of Amraja's assertion. Dr. Thibaut admits that if Saka 427 be taken as the epoch of Varaha's work, several facts, not otherwise explainable, become easy of explanation. All those considerations, together with tradition about Varaha's time, point to the conclusion we have already arrived at by discussing *ayanamsa*.

Assuming then, that the zodiac at present in use was fixed in Saka 427, let us explain a few facts connected with it. First of all, we find that in 1389 years, which have elapsed since the date, general precession has amounted to 19° 23′ 7″ ; while, had the *Surya-Siddhanta*'s year been in use throughout, the Sun must have been in error by 3° 15′ 30″ thus making the *ayanamsa* by 22° 38′ 37″ in Saka 1816 last. The amount, however, differs from that observed by 28′, -- a quantity too large to be neglected. On the other hand, if Ganesha's length of the year be taken, the error in the Sun amounts to 2° 9′ 54″, making the *ayanamsa* actually less by nearly 38′. It is remarkable that the length of the year assumed by Bhaskara makes the total 22° 12′ 21″ , nearly the same as is observed.*

From the observed *ayanamsa* and the fact of its commencement in Saka 427, the precessional rate becomes

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* The Fourmula 50 2411 t + .0001134ᵗ is adopted for calculating the general precession. See Chauvenet's Astronomy. The precession constant appears to be a little too large, as is remarked by the author. A calculation made from Bessel's constant, allowing for its variation, renders the general precession nearly 1′ less.

57"·45 This is lower than that obtained by us from the *Surya-Siddhanta*'s year, but nearly the same as we obtained from *Siromani*'s year. This discrepancy between the rate calculated from the *Surya-Siddhanta* and that found above can be explained by supposing that the *Surya-Siddhanta*'s year may not have been in use throughout the large interval of 1389 years, and that the rate of precession is not known so accurately as may be sufficient for the great length of time. The fact of Varaha's *Surya-Siddhanta* giving a slightly shorter year (as shown by Dr. Thibaut), makes no sensible difference in the result. Be the explanation what it may, it is to be observed that Chandrasekhara gives 22° 26′ as the observed *ayanamsa*, which is 15′ greater than what we have assumed. This fact shows that somehow or other, the length of the year in use was slightly less than what we find it in the modern *Surya-Siddhanta*.

At any rate, the vernal equinox in Revati did not mark the beginning of the existing zodiac. Ranganatha, a commentator of *Surya-Siddhanta*, supports us by saying that the equinox fell somewhere near Revati. For, the equinox fell on the star in Saka 498, and during the period since elapsed, the sun has moved through an excess of 3° 5′ 29" thus making the *ayanamsa* 21° 29′ 18". Even the *Siddhanta*'s position of the star leaves a difference of half a degree. So we must suppose that the star Revati was nearly a degree to the East of the initial point when the zodiac happened to commence its existing fixity.

If any use is to be made of the recorded Dhruvas of the stars, it appears to me to be the most reasonable course to select those stars which are situated near the ecliptic. For, as has been already pointed out, the errors of observation by means of rude appliances will increase with star- latitudes. Accordingly, the following twelve stars

situated within five degrees on either side of the ecliptic are given below for comparison.

Stars		Longitude in Saka 1816	Reduced longitude	Difference
Krittika (23 Tauri)	.....	58° 14″	38° 52′	19° 22′
Rohini	.....	68° 17′	47° 56′	20° 23′
Pushya (δ Cancri)	......	127° 21′	106° 0′	21° 21′
Magha	.....	148° 21′	129° 0′	19° 21′
Chitra *	.....	202° 22′	181° 13′	21° 9′
Visakha**	....			
Anuradha	......	241° 45′	224° 31′	17° 14′
Jyeshtha	.....	248° 17′	230° 41′	17° 36′
Purvashadha	.....	273° 6′	254° 30′	18° 26′
Uttarashadha	.....	278° 43′	260° 18′	18° 25′
Satatara	.....	340° 05′	319° 41′	20° 24′
Revati	......	373° 34′	359° 50′	18° 34′

The mean of the differences is 19° 18′ carrying us back to about 433 Saka. If it were possible to hit upon the stars that were taken as fundamental stars for the measurement of the Dhruvas, we could have arrived at the correct result. We might fairly take the star Magha as one of them since it is a star of the first magnitude, situated on the ecliptic, and otherwise important in Sanskrit astronomy. It would be seen from the precession of the star that the Saka year 430 is reached.

As has been already pointed out, an allowance must be made in the amount of precession deduced from the recorded Dhurvas of stars. Still, the mean general precession furnishes approximately the date of their measurement. Dr. Thibaut has employed the method to determine the

* Bhaskara's Dhruva of the star is assumed.

** I am not certain of Visakha. If it be identified with α Libra, the difference amounts to 22° 46′

"beginning of the scientific period of Hindu astronomy". From Prof. Whitney's discussion of the star-longitudes given in the modern *Surya-Siddhanta,* Dr. Thibaut places the period somewhere in the fifth century A.D. It is, however, strange that he has omitted to discuss the bearing of the Dhruvas of the seven stars he has found in the old *Surya-Siddhanta.* Omitting Aslesha which I cannot identify with certainty, the mean general precession of the remaining six amounts to about 24^{0}. This implies, then that astronomy as a science began to be cultivated in India in the second century A. D. at the latest.

We have already dwelt rather too long on the determination of the starting point. But considering the importance of the question in settling one of the fundamental preliminaries to any possible revision of our current almanacs, a word or two more on the subject may be excused.

Chandrasekhara gives two methods for determining the starting point. One is based upon a verse of the modern *Surya-Siddhanta*, which he takes to mean that the declination-circle passing through the pole-star marks the junction between Aries and Pisces (XII.61). He further cites his authority for thus interpreting the verse from *Brahma- Jamala.*

I am inclined to believe that he is mistaken in thus interpreting the sloka of the *Surya-Siddhanta**, though I have not seen *Brahma- Jamala*, nor have I an opportunity of doing so now. Taking, however, the rule for granted, it will be

* The particular sloka of the Surya Sidhanta is *"bhacakram .... Yathakramam "* (xii,73).
भचक्रं ध्रुवयोर्नद्धमाक्षिप्तं प्रवहानिलै।, पर्येत्यजस्रं तन्नद्धा ग्रहकक्षा यथाक्रमम् ।।

seen that the Dhruva of the star was 21° 42′ in Saka 1816. But from the annual variation in the star's R.A. the change in its Dhruva is nearly 3 ¾ minutes in a year. This fact alone demolishes Chandrasekhara's view.

The other method suggested is an inverse application of the sun's place, calculated after the *Surya-Siddhanta* (S. D.VI. 89). Assuming his calculated place to be correct, it is easy to find the beginning of the starting point of measurement. In the absence of a better method, this remains the only feasible course of procedure, and it is by this method that we have got the present *ayanamsa*.

It will be noticed (S.D. XII. 10) that Chandrasekhara gives 5° N. as the polar latitude of Revati. The fact is, he has given up the Revati of our ancient astronomy, for the simple reason that the *Siddhanta* Revati is hardly recognisable, and therefore practically useless. His Revati is not but η Piscium. How far this innovation will be acceptable to the public, remains to be seen.

Instances of giving old names to new stars are not rare, and this appears to be one of the main difficulties in identifying stars of different *Siddhantas*. For example, the star Pushya of Varaha-mihira's *Surya-Siddhanta* must have been a different star from the one receiving the same name in the current *Surya-Siddhanta*. For Pushya of old appears to have been Proesepe of the Greeks, while modern Pushya is δ Cancri.

It may be useful to know the stars to which Chandrasekhara applies the *Siddhanta* names. For this purpose I got a chart of the stars made by him, from which the following list is prepared.

1.	Asvini	.....	α Arietes
2.	Bharani	......	41 Arietes
3.	Krittika	......	η Tauri (Pleides)
4.	Rohini	......	α Tauri (Aldebaran)
5.	Mrigasira	......	λ Orionis
6.	Ardra	......	α Orionis
7.	Punarvasu	......	β Geminorum
8.	Pushya	......	Proesepe (in Cancer)
9.	Aslesha	......	ζ Hydri
10 .	Magha	......	α Leonis (Regulus)
11.	Purvaphalguni	......	δ Leonis
12.	Uttaraphalguni	......	β Leonis
13.	Hasta	......	δ Corvi
14.	Chitra	.....	α Virginis (Spica)
15.	Svati	......	α Bootis (Arcturus)
16.	Visakha	......	α Libra
17.	Anuradha	......	δ Scorpionis
18.	Jyeshtha	......	α Scorpionis (Antares)
19.	Mula	.....	λ Scorpionis
20.	Purvashadha	.....	δ Sagittarii
21.	Uttarashadha	....	φ Sagittarii
	Abhijit	.....	α Lyri (Vega)
22.	Sravana	......	α Aquiloe (Altair)
23.	Dhanishtha	......	α Delphinii
24.	Satataraka	....	λ Aquarii
25.	Purvabhadrapada	....	β Pegasi
26.	Uttarabhadrapada	....	α Andromeda

27. Revati	....	—	η Piscium
Agni	......	—	β Tauri
Brahmahridaya	......	—	α Aurigae (Capella)
Prajapati	.....	—	β Aurigae
Ilvaka	.....	—	Orion's belt
Lubdhaka	......	—	Sirius
Agastya	......	—	Canopus
Kratu	......	—	α Ursa majoris
Pulaha	......	—	β Ditto
Pulastya	......	—	γ Ditto
Atri	......	—	δ Ditto
Angira	......	—	δ Ditto
Vasishtha	......	—	ζ Ditto
Marichi	......	—	η Ditto
Apyavasu	......	—	5° N. of Spica; 5th mag.
Apamvatsa	......	—	6°N. of Apa; 5th mag.

The Polar longitude and latitude of Chandraskhara's Revati, as given in the work, are slightly incorrect. In a letter to me, he gave 359°10′ and 5° 30′ N. as the corrected longitude and latitude. Accordingly, the precession of the star amounted to 22° 20′ 41" in Saka 1816. These corrections were thought necessary by him in order that the observed *ayanamsa* might agree with the precession of the star as he ascertained it. But we cannot but admit that he has confounded *ayanamsa* (or sun- precession) with star-precession.* For, it is obvious, the amount of *ayanamsa* we

* An instance of an error of this kind is current in our Bengali almanacs in which the equinoxes are put two days later on account of the *ayanamsa* being taken at 20° 55′.

observe by the Sun affects only the Sun's place in finding the moment of his crossing the equinoctial points, while the general precession of the stars remains unaffected by the slight increase assumed in the length of the year. But credit must be given, him for his consistency in the view, however wrong it may be in the light of the facts disclosed.

Another important improvement made by Chandrasekhara is in the Sun's parallax. The history of his attempts at determining it is no less interesting than the results he actually obtained. The ancient astronomers of India were satisfied with taking for the parallax of each planet, 1/15th part of its mean daily motion. Accordingly, the sun's horizontal parallax was considered to be 3′ 56" and that of the Moon 52′ 42". With rough instruments at their disposal, the ancient observers could not but assign wrong values. But awkwardly enough, the parallaxes of the Sun and Moon come into every prediction of their eclipses. So while modern astronomy increases the distance of the Sun to something like 400 times the distance of the Moon, our ancient astronomers placed him no farther than 14 times this distance. Chandrasekhara has removed him to a distance of about 154 times the mean distance of the Moon.

Chandrasekhara told me that before he got the parallax, he had passed many an unhappy day. He was then very young but was anxious to know the Sun's distance. He could not even imagine how the distance could ever be known. The ancient works were dogmatic in their assertions, and did not say a word about the method employed. By his failure in approaching the problem,he became disheartened. One day thus dejected in mind, while he was

coming home, he noticed an image of the Sun projected through a narrow aperture in a fence of palm leaves close to his house. This phenomenon well known to every tyro in physical science made him reflect, and he thought that he had got a soluation of his problem. Could he but get the Sun's real diameter ! The similar triangles on the two sides of the aperture, with their bases formed by the Sun and his image, would enable him to find the distance. He hastened home, but before he looked into any work for the Sun's true diameter, he saw his error. For, was he not assuming the thing he wanted to find out ? And his exultation was followed by despair.

At this stage the problem rested for several years, till he became acquainted with rules for calculating eclipses. He found that the parallax of the Sun assumed in the *Siddhantas* was too large to make predictions of eclipses correct . The annular and total eclipses, together with those in which the Moon just grazes the shadow, were his landmarks in the determination of the problem. He was for some time in a sea of doubt. Perhaps the *Siddhantas* were wrong in the matter of parallax, as in many other matters. Perhaps his observations were not made with that degree of accuracy which was demanded by such problems.

These questions were never out of his mind for a single day through a long year. An accident favoured him. He was reading the *Atharvan Upanishad*, and was surprised to find that the Sun's diameter was not 6500 *yojanas*, as given in the *Surya-Siddhanta*, but 72000 *yojanas*. This gave him a fresh basis for calculation and he was satisfied that this diameter did not shift his landmarks to any extent which he could detect. This gave 22" for the Sun's horizontal parallax,

and with careful calculation that of the Moon was found to be 56′ 28″. Repeated observations left no doubt in his mind about the correctness of his figures. Besides, here was an authority from Sruti itself. * Taking 72000 *yojanas* for true diameter of the Sun, the distance of the sun from the earth was found to be between 105 and 106 times the Sun's diameter. In other words, the distances of the Sun and the Moon are 9510 and 61 radii of the earth respectively (VIII. & XIX.49).

The introduction is brought to a close with another topic well-known even to the boys of our elementary schools. It is about the movement of the earth, which Chandrasekhara does not admit. It is curious no doubt to hear a man given to astronomy, maintaining with all seriousness an idea which mankind has learnt to repudiate since the days of Copernicus. And there are men who, talking glibly of the earth's movements, thought that his calculations could not possibly come out right from such wrong fundamental premises. It is needless to argue the matter with those whose rudimentary knowledge of mathematics did not enable them to understand relative motion, and I would not have introduced the topic, had it not been made the sole criterion of the merits of this work.

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* Lately he learnt that European astronomers find the Sun's horizontal parallax to be about 8″, and that of the moon 56′ 40″. But he has found no reasons for correcting his figures. He says, the difference between the parallaxes of the Sun and the Moon amounts to 56′ 32″ according to European astronomy, while he finds 56′ 6″ giving results agreeing with observation. Now if the difference were changed by 26″, an annular eclipse would be changed into a partial, a partial into an annular and a total into a "touching" one.

To such critics, I would suggest that centuries elapsed during which our forefathers and the forefathers of Europeans did not even dream of the possibility of this firm and fixed earth's spinning like a top round its axis, far less of its rushing onwards with headlong speed. Chandrasekhara had not the advantage of our modern schools, and had not imbibed the spirit of taking such things on trust. His is a work of unaided effort, and it would be surprising if he, along with the schoolboy, talked of the movements of the earth. On the contrary, a miserable Uriya translation of a Bengali compilation from English popular astronomy made him a confirmed believer in the stationary condition of the earth. The arguments put forth in the book to establish the movements of the earth may be sufficient to satisfy those who do not try to realize the matter, but unfortunately were not convincing to a man who struggled hard to reconcile the new idea in all its bearings with his own observations.

Indeed, the translation and another of like nature were the only sources from which Chandrasekhara learnt something of western knowledge. They may have so far influenced him as to modify his ideas about physical astronomy, vague indications of which will be seen in certain passages of this work*, but had hardly any effect upon him as regards mathematical astronomy. The reader will find him doubtfully speaking of the satellites of some of the planets, of the proportion of land and water on the globe, and the latitudes of one hundred and eight places derived from modern Uriya maps and other sources. In these he sees no reason for disbelieving what is actually

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* See V. 79 for possible satellites ; XI.40 for phases of planets, XVII for force of gravitation, & c.

observed. But where are the observed proofs of the movements of the earth ?

To controvert the theory of the movements, he has divided his arguments to the contrary into three classes. The movements are opposed to Sastric authority, to commonsense, and to logical reasoning. To do him justice, I believe he would not hesitate a moment to modify his views, could he get the modern theory in all its details. He has thus rendered a service to us by compelling us to think. The same service was rendered by the heroic John Hampden who a few years ago essayed to prove that the world, instead of being a globe, was in reality as flat as a table. There is a tendency on the part of mankind when it has established any doctrine, to assume that it cannot possibly be disputed and so in time we even forget the arguments by which the truth was established. There is thus a need for these exceptional, and more or less original heretics who challenge our accepted doctrines.

But the peculiarity of his theory is that though the earth occupies the centre of the universe, the planets do not revolve round it. They revolve round the Sun, and the Sun taking all the planets along with it revolves round the earth (V.6.) . The Moon is of course a satellite of the earth, and makes no difference in the old and new astronomy. But where could he get the theory of the planets describing ovals round the Sun ? It is not imported from the West, but is a direct corollary from the elements of the planets themselves. For, if we plot the calculated places of a planet with respect to the Sun, the former will be found to describe something like an oval round the latter.

Indeed, I believe that this view of the solar system was held by our ancient astronomers. We cannot suppose that they could be so ignorant as not to see this simple deduction. The late Pandit Bapudeva Sastri gave other arguments in support of this doctrine of ancient astronomers (See his pamphlet *Bhubhramà- Vicara),* though I am inclined to think that the Sastri went rather too far in drawing the inference that our astronomers supposed the earth to be a planet of the Sun.

This system, formulated anew by our author, forcibly reminds one of Tycho Brahe, and bearing in mind Chandrasekhara's life, we may regard him as the veritable Tycho of India. Like Tycho, our author belongs to a noble family, which had for a series of years claimed independence. Tycho's early education was in Latin, and what Latin is to Europe, Sanskrit is to India . Young Chandrasekhara was early acquainted with the sacred lore of Sanskrit. His knowledge was so far advanced as to enable him to compose verses in it, as Tycho could in Latin. Tycho had been destined to lead a soldier's life, but his uncle who adopted him made him study law. While he was so engaged, his attention was first drawn to astronomy by the prediction of a solar eclipse in 1560 A .D. Like him Chandrasekhara received his education from his uncle, and the same search after the unknown led our Indian Tycho to penetrate the mysterious destinies of men with the help of astrology. It is said that all sciences had their origin in wonder, and it is pre-eminently true of astronomy. Nothing but star-gazing could have excited the simple yet noble utterances of the Vedic Rishis, and star-gazing has given birth to a Hipparchus and a Galileo, and may we add, to the Tycho of Europe and the Tycho of India ? The European Tycho

had Copernicus before him and the long ascendancy of the Almagest was fast coming to a close. Chandrasekhara's Almagest was *Surya-Siddhanta*, and his Copernicus was Bhaskara. Both Tycho and Chandrasekhara detected at an early age discrepancies between observation and calculation.Tycho held and Chandrasekhara still holds the same views about the solar system. The Copernican theory was before Tycho, and Chandrasekhara knew the theory of Aryabhatta, and we may add, heard not only of the diurnal rotation of the earth propounded by the renowned Aryabhatta, but of the annual revolution of the earth round the Sun from modern Geography.But both declined to accept the new theory on almost precisely the same grounds. Tycho rejected the Copernican theory chiefly for two reasons. " One reason," says Professor Young, was that it was unfavourably regarded by the clergy, and he was a good churchman. The other was the scientific objection that if the earth moved round the Sun, the fixed stars all ought to appear to move in a corresponding manner, each star describing annually an oval in the heavens of the same apparent dimensions as the earth's orbit itself, seen from the star. Technically speaking, they ought to have an annual parallax." Chandrasekhara is equally superstitious with Tycho, a staunch Hindu to the backbone. How can he disbelieve the *Sastras* ? And, besides, " the stars do not shift their places according to the seasons of the Year."*

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* Many of his arguments are directed against a misconception of the new theory. For instance, he argues that if the earth be rolling like a wheel, then it ought to move only 12,000 *krosa* per day; for that is the length of the earth's circumference. But you say, its daily motion is 8,00,000 Krosa. A stone whirled round has always the same face turned towards us; how can there be an alternation of day and night by the rotation of the earth, and so on.

The parallel drawn between Tycho and Chandrasekhara is close so far. But it fails when we remember that Tycho had the benefit of a university education, of the patronage of kings, and what is more important, that he had instruments as delicate as he could desire. Chandrasekhara has spent his life among his native hills, has seldom been five miles away from his little village and did not receive any encouragement from anybody in respect of his work. Tycho had the friendship of Frederick II of Denmark who gave him an estate in Norway; " a pension of £ 400 a year for life, a site for a large observatory, and 20,000 to build it with," and philosophers and statesmen and kings came to visit his observatory and dined at his table.

And what did our Indian Tycho receive ? He met with sneers from his equals in position, because he shook off the aristocratic prejudice against star-gazers and fortune - tellers. He had no one to encourage him in his pursuit, and no notice was taken of his work. Our Government could only confer upon him an empty title which he had never coveted. Geniuses are like delicate plants, never plentiful anywhere, and depend upon tender care for growth and development and fertility. Let me therefore hope that the past neglect of his countrymen may yet be compensated, and that better days may yet dawn upon our old and crippled observer of heavenly bodies.

KATAK

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A Modern Tycho

Siddhanta Darpana: A Treatise on Astronomy

Mahamahopadhyaya Sanamta Sri Chandrasekhara Simha
Edited with an introduction by Jogesh Chandra Ray, M.A., Professor of Physical Science, Cuttack College. (Calcutta, 1897).

Any one who reads the very interesting introudction of sixty one pages that Prof. Ray has attached to this Sanskrit work will regret very much his inability to faith on the work that follows. For therin is contained the results of the patient and industrious inquiry of one who, unaided by the accumulated knowledge of Western astronomers, resolutely set himself to solve the problem of celestial mechanics by the aid of such instruments as he could fashion himself, and where the time honoured clepsydra supplied the place of the sidereal clock. The only assistance he seems to have had were the similar rough observations of Bhaskara (born 1110) and some still older observers. Prof. Ray compares the author very properly to Tycho. But we should imagine him to be a gerater than Tycho, for without the same assistance, without the encouragement of kings and the applause of his fellows, he has advanced his facourite science quite as effectually as did the Danish astronomer. It is especially curious to notice that the system at which Chandrasekhara ultimately arrived, and the explanation he offers of it, bears a very considerable resemblance to that which Tycho taught. The author has never been able to convince himself that the Earth turns on its axis, or that it goes round the Sun but to the planets he assigned heliocentric motion, much as Tycho did.

We get some notion of the success that attended the work, and of how much it is in one man's power to accomplish, if we examine the differences between the values he assigns to some of the constants of astronomy and those in use with ourselves. The error in the sidereal period of the Sun is 206 seconds: of the Moon, 1 second: Mercury, 79 seconds: Venus, about 2 minutes: Mars, 9 minutes: Jupiter, an hour: and Saturn, rather more than half a day. The accuracy with which he determined the inclination of the planets to the ecliptic is still more remarkable. Mercury offers the largest error, and that is only about two minutes. In the case of the Solar orbit the greatest equation to the centre is only 14 seconds in error. In the Lunar theory, the revolution of the node has been concluded with an error of about 5.5 days, less than the thousandth part of the whole period: while he has independently detected

and assigned very approximate value to the evection, the variation, and the annual equation.

The main object that Chandrasekhara had before him seems to have been to correct the calendar, and regulate the daily ritual of the Hindu religion. No two almanacs, Prof. Ray tells us, agree; but any attempt to introduce the Nautical Almanac and its acknowledged accuracy would proved unsuccessful. The necessary corrections and unification must, to be acceptable, come from within and be the work of a Hindu, uninfluenced by foreign education. The work of Chandrasekhara has received the sanction of the honoured Rishis, and the adoption of the corrections which he has shown to be necessary will exert upon native society a beneficial influence, whose importance can be hardly overrated in a comminity where a correct almanac is an indispensable equipment of every household. We should like much to linger over Prof. Ray's remarks on the subject of precession and his chronological deductions. These and many other points are discussed with great ability, though Prof. Ray modestly disclaims any special astronomical capacity. The effect is to leave us at every page with a higher opinion of the author laboriously recording his observations on a palm-leaf, and unselfishly devoting his life to the services of his countrymen, who do not appreciate the nobility of the effort and the entirety of his devotion. We are in full sympathy with the editor when we writes thus of the author, of his privations and his star-gazing.

"What has he done after all? asks the impatient critic. To him I would say - Is is not enough to find in this man a true lover of science, who, regardless of other people's unfavourable opinion of his work, their taunts and dissuasions, has devoted his whole life to the one pursuit of knowledge: who has shown the way to iriginal research amidst difficulties serious enough to dishearten men in better circumstances: who has employed his time usefully, instead of frittering it away like the usual run of men of his rank on a work which guides the dai y routine of millions of his countrymen.

W. R. P.

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Siddhanta Darpana: A Treatise on Astronomy

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Edited with an introduction by Jogesh Chandra Ray, M.A., Professor of Physical Science, Cuttack College. (Calcutta, 1897).

Of all the numerous works on astronomy that have been published within the last few years, this is by far the most extraordinary and in some respects the most instructive. It is weitten in Sanskrit by a Hindu of good family of Khandapara in Orissa, and is a complete system of astronomy founded upon naked eye observations only, and these made for the most part with instruments devised and constructed by the writer himself. Those who read the sixty pages of the introduction in English, which the fellow countryman of the author, Prof. Chandra Ray, of Cuttack College, has written, will certainly regret that the barrier of an unknown tounge debars them from a more intimate acquaintance with the very striking personality that Prof. Ray described. The work to which Chandrasekhara has devoted himself, and which he has carried out with very conspicuous success is this: The native Hindu almanacs computed from the Siddhantas were falling into serious error, and no two current almanacs agreed in their computations. Chandrasekhara, therefore, has re-determined the elements of the old *Siddhanta*, but has rigorously continued himself to the ancient methods, his principal instrument of observation being a tangent-staff, devised by himself, of a thin rod of wood twenty-four digits long, with a cross-piece at, right angles to it. With these, rude means he has obtained an astonishing degree of accuracy; his values for the inclinations of the orbits of the nearest planets are corect to the nearest minute in almost every instance. The ephemerides computed from his elements are seldom more than a few minutes of arc in error, whilst the Bengali almanac may be in error as much as four degrees. To Hindus, for whom their religious observances are regulated by astronomical configurations, this work by none of themselves, a strict follower of the severest laws of their religion, and conducted throughout solely by traditional Hindu methods, is of the highest importance, as it removes the confusions which had crept into their system, without in the least drawing upon the sources of western science. But the work is of importance and interest to us westerns also. It demonstrates the degree of accuracy which was possible in astronomical observation before the invention of the telescope, and it enables us to watch, as it were, one of the astronomers of hoary, forgotten antiquity actually at his work before us to-day.

Samanta Chandra Sekhar: Life and work

P.C. Naik and L. Satpathy

Mahamahopadhyaya Sri Chandra Sekhar Simha Hari Chandan Mahapatra Samanta (1835–1904), generally known as Samanta Chandra Sekhar and more popularly as Pathani Samanta in Orissa, worked in astronomy following the traditional methods and composed a treatise entitled 'Siddhanta Darpana' in Sanskrit verse. It is a valuable work that records innumerable improvements over the ancient classics, namely, 'Surya Siddhanta' and 'Siddhanta Siromani', by incorporating original observations, calculations, instrumentation and theories. The aim of this paper is to outline and bring to the notice of a wider audience the genius of Chandra Sekhar and his contribution to astronomy. In addition, we also present a brief life-sketch of the astronomer.

India has a rich heritage of astronomy having produced great astronomers like Aryabhata, Varahamihira, Brahmagputa and Bhaskara. The genius of these luminaries bloomed at various places spread all over the country, scaling a time span of nearly 1500 years beginning with 5th century AD. Mahamahopadhyaya Chandra Sekhar Simha Harichandan Mahapatra Samanta, referred to hereafter as Samanta Chandra Sekhar, seems to be the last link of this long order of great Hindu astronomers. *Surya Siddhanta, Aryabhatiya, Panca Siddhantika, Brahmasphuta Siddhanta and Siddhanta Siromani* are prominent among the numerous astronomical works of our illustrious ancestors. *Siddhanta Darpana*[1], composed by Samanta Chandra Sekhar looks to be the latest valuable classic of high order. It is a systematic record of Samanta's lifelong research in astronomy with substantial original contribution to the field. The treatise, written in beautiful Sanskrit verse after the time-honoured Hindu tradition, has great scientific value and is also a fine piece of literary work.

Chandra Sekhar was born in the royal family of one of the princely states of Orissa, at Khandapara in 1835. He is also fondly called Pathani Samanta in the state. Chandra Sekhar, when a child, was initiated to identify stars by his father. He received primary education from a Brahmin teacher. Thereafter, he started teaching himself *Lilavati, Bijaganita, Jyotisha, Siddanta, Vyakaran and Kavya* using his family library. He was more attracted by mathematics and astronomy.

At the age of fifteen, he began to check the predictions of the *Siddhantas* with his observations. Ancient Indian works do not give details of instruments or methods of measurement explicitly, excepting hints here and there. So young Chandar Sekhar devised his own instruments. He noticed that, even classics like *Siddhanta Siromani* of Bhaskara and *Surya Siddhanta* did not agree with his observations, for the stars and planets did not appear in the sky as per their predictions.



Hence, young Chandra Sekhar assigned the job to himself and set out for observations night and day, checking every figure occurring in the earlier works.

He began recording his observations and formulations at the age of 23, and in the form of treatise, two years later. The manuscript of *Siddhanta Darpana* was ready in 1869 when he was 34. But it took another 30 years for the work, originally written on palm leaves in Oriya characters, to appear in Devanagari script printed on paper in 1899. Chandra Sekhar had *Surya Siddhanta* for his prime reference and *Siddhanta Siromani* as his guide.

This remarkable scholar and scientist, being confined to a small hilly state in a remote corner of Orissa, far away from the sphere of English education, was virtually doomed to obscurity but for his chance acquaintance with Mahesh Chandar Nyayaratna, Principal of Sanskrit College, Calcutta, who probably later on introduced him to Jogesh Chandra Ray of Cuttack College (today's Ravenshaw College). Nyanratna's efforts[2] brought him the title of Mahamahopadhyaya, conferred by the British Government in 1893.

Ray was the key person under whose supervision and involvement *Siddanta Darpana* was published in 1899 from Calcutta with the financial support of the kings of Athmallik and Mayurbhanj. It must be noted that the scholarly introduction of 56 pages in English therein by Ray[3] formed the window through which the outside world could get a glimpse of the valuable treasures contained in this monomental work couched in hardly accessible Sanskrit verse. The International journals *Nature*[4] and *Knowledge*[5] acknowledged the greatness of this contribution to astronomy by Chandra Sekhar and eulogized him in glowing terms. This Sanskrit classic underwent two Oriya translations[6,7] in 1975 and 1976. We present in the following a brief discussion of this work citing only a few important original contributions of its author.

Siddhanta Darpana

Chandra Sekhar in the 17th *Sloka* of the first chapter of the treatise enumerates the requisite characteristics of a *Siddhanta*. The work that deals with theoretical division of time from the smallest unit of *Truti* (0.274348×10^{-6} s) to *Pralaya* (10^{13} solar years), along with the motion of the celestial objects, their rotations, orbits, alignments, occultation and eclipses, etc., with the relevant mathematics like algebra, arithmetic, geometry and trigonometry and also concerns with the question of the origin of the universe is called a *Siddhanta*. One will notice that *Siddhanta Darpana* with 24 chapters and 2500 *Slokas*, out of which 2284 are Samanta's own composition and 216 are citations from the earlier authors, falls short of none of these qualifications. Chandra Sekhar has made original contributions to most of the aforesaid topics dealt with in his astronomical treatise.

It will not be out of place here to give a brief contentwise deescription of *Siddhanta Darpana*. It is broadly divided into two parts, viz. *Purvardha* (first half) and *Uttarardha* (latter half). The first half contains 15 chapters and the latter half 9. The chapters are further grouped under five sections, namely, *Madhyadhikara, Sphutadhikara, Triprasnadhikara, Goladhikara and Kaladhikara.* The first two sections deal with the mean motion and the true positions of the planets, respectively. The third section deals with motion described in terms of space, time and direction. The fourth section gives an account of the relevant mathematics like spherical trigonometry and geometry, etc. The fifth section describes different ways of reckoning time. The distribution of chapters and *Slokas* along with the title of the topic dealt with in each chapter, is given in Table 1.

The contents of *Siddhanta Darpana* look amazing as the achievement of a single mind. Chandra Sekhar has observed, verified and corrected wherever necessary all that was known to the Hindu astronomers for thousands of years. Very often he has gone beyond them to discover new phenomena and to give new formulations and comes out with predictions supposed to remain valid for at least 10,000 years to come. We give below an outline of his contributions to the four important aspects of astronomy, namely (i) observation, (ii) calculation, (iii) method of measurement and instrumentation and (iv) theory and model.

Table 1. Summary of the contents of *Siddhanta Darpana*

Name of section	*Chapter Number*	*Chapter content*	*Number of Slokas in the chapter*
Madhymadhikara	1	Description of time	55
	2	Description of *Bhagan*, etc.	25
	3	Mean planet positions	77
	4	Various corrections	57
Sphutadhikara	5	True planet positions	221
	6	Finer corrections	161
Triprasnadhikara	7	Gnomons, etc.	94
	8	Lunar eclipse	87
	9	Solar eclipse	78
	10	Parilekha description	37
	11	Transit, etc., of planets	111
	12	Alignments of planets	93
	13	Risings and setting of planet	84
	14	Phases of the moon	67
	15	Description of Mahapatra	70
Goladhikara	16	A set of questions	79
	17	Description of the Earth	159
	18	Description of the Earth (contd.)	175
	19	The celestial sphere	123
	20	Description of instruments	111
	21	Some deeper questions	249
Kaladhikara	22	Description of years, etc.	76
	23	Prayer to Purusottama	55
	24	Conclusion	156
Total			2500

Observations

As indicated in the introduction, the discrepancy between predictions of the ancient *Siddhantas* and his own observations prompted Chandar Sekhar to embark upon serious investigation. He has made it clear that, apart from purely theoretical question, nothing has been recorded in the Darpana without verification through observations.

In the third chapter of the treatise, Samanta enters into discussion on the planets. Let us look at the sidereal periods (time taken for a complete revolution with respect to 'a fixed' star) of the planets as ascertained by him. For comparison, the periods given in *Surya Siddhanta* and *Siddhanta Siromani,* the European values as known in 1899, and the modern ones are presented side by side in Table 2. It may be noted that Chandra Sekhar as arrived at the same values for the periods of the sun and the moon as in *Surya Siddhanta,* which agree with the modern values up to second and third decimal places, respectively. But in the case of the slow-moving planets like Jupiter and Saturn, his results are surprisingly in closer agreement with the modern values than those of the other two *Siddhantas.* Table 3 gives a comparison of the mean inclination of the orbits of the planets to the ecliptic. It can be seen that, of the three classified

Table 2. Sidereal periods of the planets in mean solar days. The data in the last column are taken from ref. 19 and the remaining ones from refs. 3 and 20.

Planet	*Surya Siddhanta*	*Siddhanta Siromani*	*Siddhanta Darpana*	*European values as in 1899*	*Modern values*
Sun	365.25875	365.25843	365.24875	365.25637	365.25636
Moon	27.32167	27.32114	27.32167	27.32166	27.32156615
Mars	686.9975	686.9979	686.9857	686.9794	686.97982
Mercury	87.9585	87.9699	87.9701	87.9692	87.969256
Jupiter	4332.3206	4332.2408	4332.6278	4332.5848	4332.589
Venus	224.6985	224.9679	224.7023	224.7007	224.70080
Saturn	10765.7730	10765.8152	10759.7605	10759.2197	10759.23

Table 3. Inclination of the orbits of the planets to the ecliptic. The data in the last column are taken from ref. 19 and the remaining ones from refs. 3 and 20. The quantities are in degree, minute and second.

Planet	*Surya Siddhanta*	*Siddhanta Siromani*	*Siddhanta Darpana*	*European values as in 1899*	*Modern values*
Moon	4 30 0	4 30 0	5 09 0	5 08 48	5 08 33
Mars	1 30 0	1 50 0	1 51 0	1 51 2	1 50 59
Mercury	5 55 0	6 55 0	7 2 0	7 00 08	7 00 18
Jupiter	1 0 0	1 16 0	1 18 0	1 18 41	1 18 18
Venus	2 46 0	360	3 23 0	2 53 35	3 23 41
Saturn	2 0 0	2 40 0	2 29 0	2 29 40	2 29 10

Table 4. Greatest equations of sun and moon (see text). The date are taken from ref. 3. The quantities are in degree, minute and second.

Celestial body	*Surya Siddhanta*	*Siddhanta Darpana*	*Western astronomy as in 1899*
Sun	2 10 30	1 55 33	1 55 19
Moon	5 2 46	5 1 10	6 3 41

works quoted here the values of *Siddhanta Darpana* are the closest to those of modern astronomy.

The angular position of a planet in its orbit, with respect to the force centre, is called the 'true anomaly'. The eccentric angle of the planet on the auxiliary circle is the 'eccentric anomaly'. Their difference is the equation of anomaly, the greatest value of which is a measure of eccentricity. The greatest equations given by Samanta in the case of the sun and the moon agree within seconds with the Western astronomy (Table 4). The intersection positions of the moon's orbit with the ecliptic are called *Rahu* and *Ketu* in the traditional Indian astronomy. In the Western astronomy they are called the nodes of moon. The minimum distance position of the moon. The minimum distance position of the moon from the earth is called the perigee. Table 5 shows a comparison of the sidereal periods of these nodes and the perigee.

Further, Chandra Sekhar gives a correction to be applied to *Mandocca* (the farthest position on the orbit from the force centre) of Mercury, Mars and

Table 5. Sidereal periods of the nodes (Rahu and Ketu) and the perigee in mean solar days (see text). The data in the last column are taken from ref. 19 and the remaining ones from refs. 3 and 20.

Entity	*Surya Siddhanta*	*Siddhanta Siromani*	*Siddhanta Darpana*	*European values as in 1899*	*Modern values*
Moon's nodes	6794.3948	6793.2535	6792.644	6789.270	6793.470
Moon's perigee	3232.094	3232.734	3232.657	3232.575	3232.600

Table 6. Rates of mean motion of the planets per day. The quantitites in the upper line in each row in the third and fourth column are in sexagesimal system and the ones in the corresponding lower lines are in decimal system. The data under modern value are taken from ref. 19 and those due to other Siddhantas from ref. 20. The quantities are in degree, minute and second

Planet	*Modern value (Lahiri)*	*Brahmagupta Sripati Bhaskar*	*Samanta Chandra Sekhar*
Sun	0 59 02.2	0 59/8/10/21	59/8/10/24/12/30/4/0/4
		0 59 8.1725	0 59 8.1733912182
Moon	12 10 35.0	13/10/34/53/0	13/10/34/52/03/49/08/02/16/10/11
		13 10 34.8833	13 10 34 8677275173
Mars	0.31 26.5	0/31/26/28/7	0.31 26.5018877228
		0 31 26.4686	
Mercury	4 05 32.4	4/05/32/18/28	
		4 5 32.3077	
Jupiter	0 04 59.1	0/04/59/9/9	0/04/59/05/37/0/36/41/17/01/51
		0 04 59.1525	0 04 59.0936139473
Venus	1.36 07.7	1/36/7/44/35	
		1 36 7.74305	
Saturn	0 02 01.9	0/20/0/22/51	
		0 2 0.380833	0/02/0/26/55/02/53/21/02/04/54
Moon's nodes	–0 03 10.6	0/03/10/48/20	0 2 0.448624511
		0 30 10.8055	0 03 10.7946631769

Saturn and calls it '*Paracca correction*'. The maximum values of these corrections are 12°20′, 7°30′ and 5° for the above three planets, respectively.

In observation of the moon, Samanta Chandra Sekhar noticed three important irregularities. They are *Tungantara* (evection), *Pakshika* (variation) and *Digamsa* (annual equation). In terms of modern understanding[8, 9], recognition of these three irregularities is as follows:

(i) Tungantara (evection) is the largest of the irregularities. It depends on the changing position of the apse line (the line joining the maximum and the minimum distance position from the force centre, i.e. the earth) in successive lunar months. It further has the following two effects:

(a) The apse line advances as a whole while undergoing oscillatory motion. However, it retrogrades when the perigee (maximum distance from the earth) occurs at the first and third quarters of a lunar month.

(b) The eccentricity also oscillates attaining a maximum of 0.066, when perigee occurs at new or full moon, and a minimum of 0.044, when it occurs at first or third quarter. This perturbation effectively puts the moon forward or backward from the expected position by about a degree. The maximum

of this irregularity according to modern astronomy is 1°17′, whereas Samanta Chandra Sekhar observed it to be at most 2°40°.

(ii) *Pakshika* (variation). From new moon to full moon, i.e. during the bright fortnight of the lunar month, the attractive force of the sun on the moon retards it. And during the dark fortnight, the effect is opposite and the moon is accelerated. This causes a maximum shift in the position of the moon by 39′31″ according to modern astronomy. Samanta's value of 38′12″ for maximum of this effect is surprisingly close to the modern value.

(iii) *Digamsa* (annual equation). This is another irregularity in the position of the moon, which arises due to variation in sun-moon, which arises due to variation in sun-moon distance as the earth orbits round the sun. Obviously, its period is one year. The maximum value of this correction is 11′9″ as per modern astronomy, and Samanta's value of 12′ is fairly close to it.

Chandra Sekhar has clearly mentioned in *Siddhanta Darpana* that *Tungantara* was known to his predecessors. However, J.C. Ray in his introduction to *Siddhanta Darpana* says: 'In computing the moon's place, Chandra Sekhar has discovered some original corrections--original in the sense of their having been unknown to the ancient astronomers of our country[9]. Even Burgesss[10] in his English translation of *Surya Siddhanta* says that the Hindus did not take any notice of evection. However, the latest view on this issue is that of P.C. Sengupta[11], who concludes that evection and variation were introduced by Munjala and Bhaskara. Nevertheless, it is definite that Samanta Chandra Sekhar was the only Indian astronomer of traditional school to have discovered *Digamsa* and took into account all the three irregularities and measured them with utmost accuracy. In passing, it will not be out of place to mention that Tycho Brahe was the first Western astronomer to have detected and measured all these three irregularities.

Another improvement made by Chandra Sekhar was in the case of parallaxes of sun and moon. Parallax is defined as the angle subtended by the radius of the earth at a heavenly body. The earlier *Siddhantas* took it to be 3′56″ at sun and 52′42″ at moon. But since these are the quantities that enter into calculation of eclipses, Chandra Sekhar changed them to make the predictions agree with the observations. The ancient Indian astronomers place the sun at a distance not more than 14 times that of the moon from the earth. Chandra Sekhar hiked this ratio by more than ten times, to 154, which is much closer to the modern value of 390.

Calculation

Astronomy is a science in which observation goes hand in hand with calculation. Besides a thorough knowledge of the motion of the celestial objects, it requires sufficient computational skill to tackle the vast multitude of big bumbers. We will see in this section that Chandra Sekhar was extraordinary in this respect. Very often he has gone beyond his predecessors in precision of computation and in giving new methods of calculation.

To get positions of planets one has to do extremely careful calculations. In the traditional method one first calculates as mean position and then applies corrections to arrive at the true position. The calculation of mean position requires a mean rate of motion. Works in traditional astronomy clearly give these rates as accurately as possible. The earlier works are found to give these rates (mean angular displacements per day) at best to five places in the sexagesimal system. But Chandra Sekhar gives these rates to ten places in the same system. For comparison, we have presented in Table 6 the modern values of these rates in the decimal system and also gives the traditional data converted into decimal system.

Chandra Sekhar recognized that, in addition to the usual corrections to the mean position, further final corrections are needed from time to time to make accurate predictions. For each planet, he has provided such a correction to be applied for hundred million (one *Arbuda*) years. There are as many as 55 tables, each on an average having 50 numbers sometimes given up to five places in sexagesimal system. These tables appear to be a challenge for one's unaided computational skill.

Regarding the measurement of longitudes of the celestial bodies, there is a fundamental difference between the Western system and that of the Hindus. In the former system, it is measured with respect to the vernal equinox, *i.e.* one of the point of intersection of the celestial equator with the ecliptic. The Hindu system measures it with respect to a fixed point (a particular star) on the ecliptic. It is the starting point of zodiac and its longitude is the *Ayanamsa.* But it may be pointed out that the axis of the earth undergoes a precessional motion with a period of about 25,800 years. This causes a shift in the position of the equinox and also in that of the reference star, which according to the traditional Indian astronomy is called *Ayancalana.* So, this effect must be taken into account in fixing the *Ayanamsa* of the reference point. A correct determination of the *Ayanamsa* involves a number of factors like the rate of pression, the exact length of a year, the year of the zero *Ayanamsa* and the star of reference. A critical discussion of the matter is found in the introduction to *Siddhanta Darpana*[3]. *Surya Siddhanta, Soma Siddhanta, Sakalya Siddhanta,* and *Laghu Vasistha,* etc., have given the rate of precession as lying in the rage 54″ to 46.25″ per year. However, *Bhasvati* and *Graha Laghava* have found the value to be nearly 60″. But Chandra Sekhar's value is 57.615″ per year.

The modern value of the precessional rate is, however, 50.3″ per year. Thus, it appears that the Indian rates quoted above are in disagreement with the modern value. Therefore, it is desirable to understand how such varying rates of precision which sensitively affect the fixation of *Ayanamsa* could give meaningful prediction in the ancient Indian astronomy. Ray gives a solution to this puzzle. He points out that the Indian astronomers take the sidereal year for calculation of the rate of precession, in contrast to the tropical year, taken in the West. Since the sidereal year is longer by a few minutes, the sun advances by an amount of 8.4″ during this interval of time difference. This has an effect on the calculation of precession of equinox and the amount has to be deducted from the rates given by various authors. When this correction is taken into account, Samanta's value turn out to be 49.179″ per year, which is much closer to the modern value.

Chandra Sekhar has devised a diagramatic or graphical method (*Parilekha*) for calculations of eclipses and many other phenomena. In this method, when the nature and periodicity of the motion of the heavenly bodies are known, one can simulate the phenomena by constructing geometrical diagrams on the plain surface and use them for computation of dynamical quantities. This method might be akin to the numerical evaluation of integrals. Especially, he tackles the calculations of the three well-known irregularities of the moon with simple geometrical arguments. It is needless to say that his calculations of eclipses are accurate and agree with observations. It may be noted here that this has been the guide in the preparation of the almanac used in Orissa since about 1870.

Before concluding this section, we would like to point out at least two facts of mathematical interest from *Siddhanta Darpana.* Samanta does not accept the value of π as 22/7; instead, he takes it to be 3927/1250 and also 600/191. He seems to have provided a new method for computing the cube root of numbers which is different from that of Bhaskara.

Measurement and Instrumentation

Chandra Sekhar was unaware of the scientific and technological developments that had already taken place in the West. He had not seen or even heard of a telescope until his very old age. So he employed the traditional methods for astronomical measurements. He had devised some new instruments for the purpose. It is a remarkable point that Jai Singh in the 18th century built a number of observatories in the northern part of the country. His instruments for measurements in these observatories are rather gigantic. In sharp contrast, Chandra Sekhar, who worked about 150 years later, fabricated quite simple and small devices and made accurate observations.

Before attempting to give an account of his astronomical *Yantras,* we would like to mention as interesting fact about Chandra Sekhar's ability for measurements. The children at primary schools in Orissa today read it as a myth that Samanta measured

the heights of distant mountains with a pair of tiny sticks. The simplest of his stock instruments is the *Sanku* (pole). Of course, it was used also by the Greeks under the name '*gnomon*'. It is not difficult to find out the latitude of a place by observing the shadow of the *Sanku,* cast by the sun. But more interesting is, Chandra Sekhar's calculation of local time from the shadow.

Chandra Sekhar's most talked of instrument is the *Mana Yantra.* Details of construction of this instrument have been described in *Siddhanta Darpana.* Chandra Sekhar used this *Yantra* as a multipurpose device. A simpler version of this *Yantra* is a two-stick arrangement in the form of 'T', which he could fabricate quickly, and measure the height and distance of mountains, etc., whenever occasion demanded.

Samanta has described in detail the construction techniques for varieties of *Gola-yantra* that he used to measure the positions of planets. There is a mention of as many as ten different devices for measurement of time in *Siddhanta Darpana.* Models of some of these, including a *Gola-yantra* have recently been exhibited at the Regional Science Centre. Bhubaneswar. Samanta Chandra Sekhar has devoted a full chapter of *Siddhanta Darpana* to describing the construction and use of instruments. Such instruments, by today's standard, are crude, by using them he could arrive at results in close agreement with modern values, primarily due to his skill, attained through long years of dedication and practice.

Theory and Model

The most prominent of Chandra Sekhar's theoretical contributions is his model of the planetary system, which is different from those of his predecessors in India. Samanta supported a stationary-earth hypothesis, with sun, moon and starts revolving around the earth. But it has the novel feature that planets like Mercury, Venus, Mars, Jupiter and Saturn go around the sun, and the sun moves around the earth together with these companions. This is evident from the following *Slokas of Siddhanta Darpana* :

तत्रमध्यम मार्त्तण्ड: परितोमण्डलंभुव:
भ्रमन् ताराखेचराणां कक्षामध्यस्थ उच्यते।
तं भ्रमन्तो महीजाद्यास्तत्सडेन भुबं पुन:
परिक्रामन्ति यत्तस्मात् स प्रोक्त: सर्बकर्षक:।

S.D. Ch. V Slokas 6 and 7

Thus, he assigned heliocentric motion to the planets. Incidentally, a similar model was proposed by Tycho Brahe in the West in the late sixteenth century. A recent work by Ramsubramanian *et al.*[12] brings to light that a similar model of the planetary system was given by Nilakantha Somasutvan of the Kerala school by 1500 AD.

Conclusion

We have attempted to give a brief sketch of the extraordinary life and work of Samanta Chandra Sekhar here. Unforunately, due to various historical and geographical reasons, his true position in ancient Indian astronomy has not been ascertained so far. Ray has drawn a nice parallelism between the life and works of Samanta Chandra Sekhar and of Tycho Brahe. The journal *Nature* comments[4]: 'Prof. Ray compares the author very properly to Tycho. But we should imagine him to be greater.' The importance of Samanta's work and the quality of his observations with naked eye have got true recognition through the comments made in the journal *Knowledge*[5]: 'Of all the numerous works on astronomy that have been published within the last few years, this is by far the most extraordinary and in some respects the most instructive. ...It is a complete system of astronomy founded upon naked-eye observations only. ...The work is of importance and interest to us Westerners also. It demonstrates the degree of accuracy which was possible in astronomical observation before the invention of telescope.' Here it will be probably fair to sate that Samanta Chandra Sekhar belongs to the same class of Indian astronomers as Aryabhata, Varahamihira, Brahmagupta and Bhaskara.

It is unfortunate that Chandra Sekhar is almost unknown outside Orissa. This has so happened probably because he lived and worked during a period

which was about 300 years after Orissa lost its pristine glory and preeminent position in the Indian subcontinent[13-16]. Although Orissa came under British rule in 1803, it continued to remain in virtual darkness during the lifetime of Samanta, being deprived of the advantage of modern education.

Almost a century has passed since the publication of *Siddhanta Darpana*. Its author passed away in 1904 living in the midst of poverty and struggle. The only recognition for the scientist during his lifetime was the acceptance of his astronomical prescriptions for regulation of the rituals at the Jagannath temple and the award of the title of Harichandan Mahapatra by Gajapati king of Puri in 1870. Of course, the title of Mahahopadhya was conferred upon him by British Government in 1893.

It is a matter of some relief that Kochhar and Narlikar[17] and SriRam[18] have recently referred to the work of Samanta Chandra Sekhar. Nevertheless, Siddhanta Darpana continues to serve the people of Orissa by providing the basis for the preparation of its almanac.

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Samanta Chandra Sekhar : The great naked eye astronomer *

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Abstract. Samanta Chandra Sekhar (1835-1904), popularly known as Pathani Samanta in Orissa, worked in astronomy following traditional methods, completely unaware of the telescope and other aids developed in the west. He took observations with ingenious and handy instruments, all fabricated by himself. His study and observations are recorded in an invaluable classic, the Siddhanta Darpana, composed in beautiful metrical sanskrit verse. It contains many original contributions of Samanta in observation, calculation, instrumentation, theory and model. Hence it shows appreciable improvements over the earlier classics like Surya Siddhanta and Siddhanta Siromani. The results of Chandra Sekhar's observations are often comparable with modern data and his predictions in positional astronomy are in fair agreement with actual occurrence of astronomical events, even today. In view of all these, Samanta Chandra Sekhar stands out as a great naked eye astronomer who had reached the limit of accuracy in observation. The aim of this paper is to bring out the merits of Siddhanta Darpana and the genius of its author to the notice of a large scientific community.

Key words : Traditonal Indian Astronomy - Siddhanta Darpana - history

1. Introduction

Astronomy began with the very dawn of civilisation by the observation of celestial objects and phenomena through the naked eye. It continued to remain so till the mid seventeenth century when Galileo invented the optical telescope that ushered a new era in observation. Galileo's discovery brought about rapid progress in astronomy in the West. On the other hand, it is well known that India has a great heritage in this field, beginning with the period of Vedas upto the present century. The genius of astronomers like Aryabhata, Varahamihira, Brahmagupta, Bhaskara, Satananda, Sripati and others blazed from various corners of the country at different periods of history. All of them were naked eye observers.

* The author's dedicate this atricle to late Professor N. C. Rana

Mahamahopadhyaya Chandra Sekhar Simha Harichandan Mahapatra Samanta, referred to here after as Samanta Chandra Sekhar seems to be the last link of this long order of great Hindu astronomers. The Surya Siddhanta, Aryabhatiya, Pancha Siddhantika, Brahmasphuta Siddhanta, Siddhanta Siromani are prominent among the numerous important astronomical works of our illustrious ancestors. The Siddhanta Darpana, composed by Samanta Chandra Sekhar (Singh Samanta 1899) looks to be the latest valuable classic of high order. It is a systematic record of Samanta's life-long research in the field, with substantial original contributions. The treatise has been written in beautiful, metrical sanskrit verse, after the time honoured Hindu tradition and is a fine piece of literary work apart from being of appreciable scientific value. Further, the work enjoys practical importance even today, for the most widely accepted almanac in Orissa is prepared as per its prescriptions. Therefore, it has deep rooted social relevance as well. It is needless to say that the calculations and predictions of Siddhanta Darpana continue to agree with the observations keeping its almanac in vogue for more than hundred years.

Before attempting to give an humble account of Samanta's contribution to astronomy we would like to give a sketch of his early life. Chandra Sekhar was born in the royal family of Khandapara, one of the princely states of Orissa, in 1835. Nick-named as Pathani by his parents, he is fondly called Pathani Samanta in the state. Chandra Sekhar was initiated to identify stars by his father when he was a child. He received primary education in mother tongue Oriya and Sanskrit from a brahmin teacher. His formal education ended there. Then young Chandra Shekar started teaching himself Lilavati, Bijaganita, Jyotisha, Siddhanta, Vyakarana and Kavya, using the family library. During these studies, he was attracted more by mathematics and astronomy.

At the age of fifteen, Chandra Sekhar learnt the meaning of lagna (the ascendant) and the method to calculate the ephemerides of planets. He found that the stars and planets did not rise and appear at positions predicted by the Siddhantas. Traditional texts on astronomy generally do not give details of the instruments to be used for such observations and the methods of measurements explicitly, excepting occasional hints here and there. Therefore, he had to devise instruments by himself.

Now he set out for observation, night and day, checking the figures occurring in the earlier works. He found that, even Surya Siddhanta and Siddhanta Siromani were not always correct. Besides, all these classics authorise one to add corrections as and when necessary. Therefore, Chandra Sekhar took the task of correction onto himself. He began recording his observations and making formulations of the ideas at the age of twenty three and started putting them in the form of a treatise some three years later. The complete script of Siddhanta Darpana was ready by 1869, when he was thirty four. But it took another thirty years for the work originally written on the palm leaves in Oriya character to appear in Devnagari script, printed on paper in 1899. Chandra Sekhar had the Surya Siddhanta for his prime reference and Siddhanta Siromani for his guide.

This remarkable scholar and scientist, confined to a small hilly state in the remote corner of Orissa, far away from the sphere of English education, was virtually doomed to obscurity, but for his chance acquaintance with Sri Mahesh Chandra Nyayaratna, Principal of Sanskrit college of Calcutta, who probably later on introduced him to Prof. Joges Chandra Ray of Cuttack College

(today's Ravenshaw College). Sri. Nyayaratna's efforts (Mishra 1932) brought him the title of Mahamahopadhyaya conferred by the British Government in 1893. Of course, earlier the Gajapati Raja of Puri bestowed upon him the title of Harichandan Mahapatra.

Prof. Ray was the person under whose involvement and supervision, Siddhanta Darpana was published in 1899 from the Indian Depository in Calcutta, with the financial support of the King of Athmallik and partly by the King of Mayurbhanj. It must be noted that the scholarly introduction of fifty six pages in English, therein, by Prof. Ray (Ray 1899) formed the window through which the English knowing world could get a glimpse of the valuable treasures contained in Siddhanta Darpana, otherwise couched in almost inaccessible Sanskrit. The international journals, Nature[1] and Knowledge[2] have acclaimed this work (Siddhanta Darpana) in glowing terms. Lately, Siddhanta Darpana has gone through two Oriya translations (Singh Samanta 1975, 1976). We present in the following a brief review of this work, citing only a few important original contributions of the author.

2. Siddhanta

यत्रत्रुद्याादिकाल : प्रलयचरमक : खेचराणां प्रचार :
प्रश्नाश्चैवोत्तराणि द्विविध - गणितमप्युद्भबो भूतराशे : ।
स्थानंभू-भग्रहादेर्ग्रहण - खगयुति - ज्या - धनुष्कर्मयन्त्र -
क्षेत्राद्यं गद्यते सद्गणकगणबरैरेष सिद्धान्तउक्त : ।

Chandra Sekhar enumerates the requisite characteristics of a Siddhanta, in the 17th sloka of the first chapter of Siddhanta Darpana given above. The work that deals with time, beginning from the smallest unit of, "truti" (0.274348×10^{-6} sec.) to "pralaya" (10^{13} solar years) alongwith the motion of celestial objects, their revolution, orbits, alignments, occultation and eclipses etc., with the relevant mathematics like arithmetic, algebra, geometry and trigonometry, and also concerns with the question of the origin of the universe, is called a Siddhanta.

There are quite a number of Siddhantas in India, which fall mainly into two classes; (i) Siddhantas like Pancha Siddhantika, Siddhanta Siromani etc. with definite authors and (ii) Siddhantas like Surya Siddhanta, Vyasa Siddhanta etc., ascribed to various divine sources, in the traditon of the Vedas and the Upanishads. The number of the latter category of works is eighteen which is the same as the number of Hindu puranas. It is needless to say that, all these works fulfill the scriptural norms cited above.

One will notice that, Siddhanta Darpana with 24 chapters comprising 2500 slokas out of which 2284 are Samanta's own compositions and 216 citations from the earlier authors, falls short of none of these qualifications. Chandra Sekhar has original contributions in most of the aforesaid topics dealt in his treatise. The whole contents of Siddhanta Darpana is divided into five sections, namely, Madhyadhikara, Sphutadhikara, Triprasnadhikara, Goladhikara and Kaladhikara. The

(1) Nature, 1899, 52, 436
(2). Knowledge, 1899, XXII, 257

first two sections deal with the mean motion and true position of the planets respectively. The third section deals with the motion described in terms of space, time and direction. The fourth section gives an account of the relevant mathematics like spherical trigonometry and the fifth describes different ways of reckoning time. The distribution of chapters (a chapter in Siddhanta Darpana is called a Prakasha) and slokas into sections in the treatise is as in Table1.

Table 1. Section wise distribution of chapters and slokas in Siddhanta Darpana.

Serial No.	Section	Chapters included	Number of slokas
1	Madhyadhikara	1-4	204
2	Sphutadhikara	5-6	372
3	Triprasnadhikara	7-15	736
4	Goladhikara	16-21	901
5	Kaladhikara	22-24	287
	Total	24	2500

It will not be out of place to mention here that the sections and sequences given above are followed more or less in most Siddhantas.

The material content of Siddhanta Darpana looks amazing as the achievement of a single mind. Chandra Sekhar has observed, verified and corrected wherever necessary, all that was known to the Hindu astronomers for thousands of years. Very often he has gone beyond his predecessors to discover new phenomena, advance better formulations and come out with results in the form of stupendous tables, as corrections to be applied to keep calculations agree with observation for ten thousand years to come. We out-line below Samanta's contributions to four important aspects of astronomy, namely (i) observation (ii) calculation (iii) method of measurement and (iv) theory and model. We briefly deal with these aspects of the work in the following sections.

3. Observation

Samanta Chandra Sekhar was an ardent observer throughout his life. He has made it clear that, barring purely theoretical questions, he has not recorded a single fact in Siddhanta Darpana, without observation. Samanta spent sleepless nights for making observations and ultimately this told upon his health causing dyspepsia with colic that remained his life companion. But this frail figure of a man, has given incredible accurate data that fairly tally even with modern observations. We cite in the following (Tables 2 and 3), the sidereal periods and inclination of orbits of the planets. It may be remembered that the Sun, Moon and two nodes of Moon (Rahu and Ketu) alongwith the five naked eye planets constitute the system of navagraha (nine planets) in Hindu system of astronomy.

The figures quoted as modern data in the table are taken from Lahiri (1994). The data quoted against the traditional works are taken from Ray (1899) and Burgess (1860). The results presented as the European values as on 1899 are taken from Ray (1899). One may notice that Siddhanta Darpana agrees with the modern measurements more closely in most of the cases. Even in some

cases like the sidereal periods of Moon's node and the inclination of orbit of Venus the modern values are closer to that of Samanta than the European values of 1899. It is surprising how Samanta Chandra Sekhar could attain such accuracy.

Table 2. Sidereal periods of planets in days.

Planet	Surya Siddhanta	Siddhanta Siromani	Siddhanta Darpana	European value as in 1899	Modern value
Sun	365.25875	365.25843	365.25875	365.25637	365.25636
Moon	27.32167	27.32114	27.32167	27.32166	27.3216615
Mars	686.9975	686.9979	686.9857	686.9794	686.97982
Mercury	87.9585	87.9699	87.9701	87.9692	87.969256
Jupiter	4332.3206	4332.2408	4332.6278	4332.5848	4332.589
Venus	224.6985	224.9679	224.7023	224.7007	224.70080
Saturn	10765.773	10765.8152	10759.7605	10759.2197	10759.23
Moon's Nodes	6794.3948	6792.2535	6792.644	6793.270	6793.470

Table 3. Inclinations of the orbits of planets to the ecliptic.

Planet	Surya Siddhanta	Siddhanta Siromani	Siddhanta Darpana	European value as in 1899	Modern value
	° ' "	° ' "	° ' "	° ' "	° ' "
Moon	4 30 –	4 30 –	5 09 –	5 08 48	5 08 33
Mars	1 30 –	1 50 –	1 51 –	1 51 2	1 50 59
Mercury	5 55 –	6 55 –	7 2 –	7 00 08	7 00 18
Jupiter	1 0 –	1 16 –	1 18 –	1 18 41	1 18 18
Venus	2 46 –	3 6 –	3 23 –	3 53 35	3 23 41
Saturn	2 0 –	2 40 –	2 29 –	2 29 40	2 29 10

Table 4. Comparison of r/R ratio (See Text).

Planet	Siddhanta Siromani	Siddhanta Darpana	Modern value
Mars	1.5	1.518	1.52
Mercury	0.37	0.3875	0.387
Jupiter	5.3	5.21	5.2
Venus	0.716	0.725	0.723
Saturn	9	9.47	9.5

Table 5. The greatest equations of Sun and Moon.

Celestial Body	Surya Siddhanta	Siddhanta Darpana	Western astronomy as in 1899
	° ' "	° ' "	° ' "
Sun	2 10 31	1 55 33	1 55 19
Moon	5 2 46	5 1 10	6 3 41

It is well known today that the planets go round their force-centre (the Sun) in ecliptic orbits. But, for traditional Indian astronomers, who depend purely on their observation from the earth, the motion of planets (nava graha) was a great puzzle. It was the same also for the Greeks. The observed deviation of their orbits from circles was explained in India to be due to fictitious centres of attractions "stationed in the zodiac called the conjuction (sighrochcha), apsis (Mandochcha) and node (pata" (Surya Siddhanta, Ch.II verse-1). One draws epicycle circles on the mean circular orbit of planet around the Earth and makes necessary corrections to get the true position of planet. Most of the Siddhantas give the dimension of these circles. A possible test of the correctness of these observational result is the calculation of (r/R) ratios and their comparision with the modern values, where r & R, refer to the radii of the sighra circle and that of the mean planet orbit respectively. Table 4 shows a comparison of these ratios. Siddhanta Darpana again has a closer agreement with the modern values. Related with this fact are the orbital elements like eccentricity of orbits and the greatest equations of anomaly. The greatest equations of Sun and Moon obtained according to Siddhanta Darpana are compared with those of western values and Surya Siddhanta in Table 5.

In connection with the corrections to be applied to the mean positions to get the true planets, Samanta has made an original observation contained in the following slokas.

कुजज्ञशनिमन्दानां प्राक्-पश्चाच्चलनेक्षणात् ।
ज्ञशीघ्रस्यापि कुसोहन्य : परोच्चाख्य : सुरोमचा ॥

सषड्भ : सूर्य्यमध्य : स्याद्भूमिपूत्रपरोच्चक : ।
ज्ञपरोच्चो मृदो : शीघ्र : शीघ्रस्यापि मृदूच्चक : ॥

धृत्यं-शोनः शनिर्मध्य : स्वबन्दस्य परोच्चक : ।
मन्दोच्चादिबदेतेहपि न दृशद्या : केलमूर्त्तच : ॥

(S. D. Ch. V. Slokas 76,77,78)

which means that he observed the motion of apsides and conjuctions of Mars, Mercury and Saturn to be both forward and backward. Therefore, he introduced *Parochha*, a new centre of attraction to explain his observations. He has given the parochcha correction to be applied to the planets Mercury, Mars and Saturn, the maximum of which are 12° 20'. 7° 30' and 5° respectively.

However, in the case of Moon, Chandra Sekhar noticed the three important perturbations, Tungantara (Evection) Pakshika (Variation) and Digamsa (Annual equation) as declared in the following sloka.

तुङ्गान्तार पाक्षिकनाभधेचं फलं दिगंशाख्य मदस्तुरीचम् ।
कमेण बक्ष्यामि निरीक्ष्य यत्नाच्चित्रांगतिं रत्रिपतेश्चिराच ॥

(S.D. Ch. VI Sloka 6)

"Strange is the motion of the Moon. I have observed it for long time. I am giving here three more corrections namely, Tungantara, Pakshika and Digamsa in addition to the Manda correction

of the Moon" Chandra Sekhar clearly says that the maximum value of 160' (2° 40') of Tungantara was known to his predecessors in the sloka.

खाङ्गेन्दु लिप्तं चिरकालतोहभू त्तद्बृद्धिहासा बुररी क्रिययेताम् ।
इत्यादि पूर्बोक्तिभिरेब सिद्धं बीजै : स्वकालाक्षिसमै : स्फुटत्वम् ॥

(S. D. Ch. VI Sloka 51)

But J. C. Ray in his "Introduction" to Siddhanta Darpana says, "Pandit Sudhakar Dwivedy informs us in his excellent manual called Ganaka-tarangini, that Munjala (A.D. 933) had something like evection in his Karana, named Laghumanasa. He appears to be the oldest Hindu astronomer who detected the irregularity, though curiously enough, his successors, including Bhaskara left it unnoticed". Burgess in Surya Siddhanta (Burgess 1860) mentions, "Ptolemy also adds to the Moon's orbit an epicycle, to account for her second inequality, the evection, the discovery of which does him so much of honour. Of this inequality, the Hindus take no notice." Ray clearly states, "Chandra Sekhar has discovered some original corrections - original in the sense of their having been unknown to the ancient astronomers of our country". However, Sengupta (1934) in his appendix to translation of Khandakhadhyaka concludes that evection and variation were introduced by Munjala and Bhaskara. But it is definite that Samanta Chandra Sekhar is the only Indian astronomer of traditional school to have clearly observed all the three irregularities and measured all of them with utmost accuracy. The maximum of Tungantara according to modern astronomy (Jones 1934, Barlow 1944) is 1° 17' whereas Samanta gives the maximum value of 2° 40'. The maximum value of Pakshika and digamsa, as observed by Chandra Sekhar are 38' 12" and 12' against 39' 31" and 11' 9" of modern values.

It may appear from the figures quoted above that Samanta's maximum value for the evection is nearly twice the modern value. This apparent discrepancy in Samanta's observations has been explained by Ray (1899). He points out, "The amount of greatest equation of moon is 6° 18' and maximum evection 1° 20', making the total of 7° 38'. Chandra Sekhar has 5° 1' as the greatest equation and 2° 40' as the greatest Tungantar, making the total 7° 31'. Therefore result of Chandra Sekhar's observations are in surprisingly close agreement with the modern values. In passing, it may be remarked that Tycho Brahe was the first Western astronomer to have detected and measured all the three irregularities.

The circumferences of the orbits of Moon, Sun and stellar universe are given below, as per the estimate of the main Siddhantas (Table 6) with the earth taken as centre. It is straight forward to reach an estimate of their distances from the common centre. More important is the ratio of the distances of the Sun and Moon, which is given in the last row. It may be noticed that the ancient Indian Astronomers placed the Sun at a distance not more than 14 times that of the Moon from the Earth. However, Chandra Sekhar hiked this ratio by more than 10 times to 156 which is much closer to the modern value of 390.

Chandra Sekhar has given positions of junction stars of 28 nakshatras (including Avijit) which are not always same as in earlier literature. There is a comparative study of the matter in a recent work (Mishra 1995) which concludes that Chandra Sekhar's values for coordinates of the junction

stars are significantly closer to the modern data.

Finally, it will not be out of place to mention that conjunction, occultation and transits of celestial objects have been dealt in detail in a number of works in Hindu astronomy. Of them all, the transit of Mercury and Venus are important in the sense that they cause, some sort of solar eclipses. Transit of Mercury cannot be sighted in the naked eye, whereas the Transit of Venus has been recorded by observers in the West. Samanta Chandra Sekhar seems to be the only traditional astronomer to have left a record of having observed the 1874 (December) Venus transit visible from India in the following sloka.

दृष्टं शुक्रस्य गाढास्तमयसमयजं मण्डलं चण्डभानौ कीटांशे पञ्चबिंशे गत बतिं कलितोहर्थाहद्रिगोहब्ध्यब्दबृन्दे ।
भास्वद् बिष्कम्भदन्तां श्मितमित इदं खार्थषट् योजनं स्यात् । इत्यन्यजज्ञेयमस्मांत्तनब इन - तंनोस्तारका : कोर्ग्रहा : स्युः ।

(S. D. Ch. XI, Sloka 110)

Of course, the next transit of venus occurred in December, 1882, but was not visible from India and so there is no record of it in Siddhanta Darpana.

4. Calculation

Observation and calculation go side by side in astronomy. As indicated in section-1, discrepancy between the prediction of siddhantas and his own observations prompted Chandra Sekhar to write Siddhanta Darpana. Particularly, calculation of positions of planets demands prime attention of a beginner. Predicting their positions is a very complicated process. Usually, the traditional astronomers assume an epoch, at the beginning of which all the planets started their revolutions (bhagans). They take a mean rate of motion for each planet, then multiply the rate with the number of bhagans during the epoch, and get the mean position of the planet on a particular day with respect to a location chosen as the reference point on the Earth.

It is also a fact that, the traditional astronomical works fall into three categories depending upon the choice of the epoch. Tantra and Karans choose beginning of the Kali Yuga and some recent date respectively to mark the epoch where as Siddhantas take the period to be a Maha Yuga (sum of the period of the four yugas). But Samanta Chandra Sekhar takes the epoch from the beginning of the Kalpa (1000 Maha Yuga). He has calculated the number of sidereal revolutions of the planets during the Kalpa.

He gives the mean rates of motion (average angular displacement per day) of the planets upto ten places in the sexagesimal system, whereas the earlier siddhantas give these figures to five places at best. In Table 7 we have presented these data including the modern ones (Lahiri 1994) for comparison.

One may note that Samanta does not give the rate for Mercury and Venus. Instead he gives the rates of their sighrochcha in sexagesimal system to be respectively, 4° / 05' / 32"16 / 07 / 59 / 43 / 42 / 44 and 1° / 36' / 07" / 47 / 57 / 50 / 39 / 32 / 31 / 35. He considers these rates to be more

Table 6. Circumferences of the orbits in Yojanas. One Yojana = 5 miles approximately.

Planet etc.	Surya Siddhanta	Siddhanta Siromani	Siddhanta Darpana
Moon (= p)	324000	324000	306000
Sun (= q)	4331500	4331497.5	47800800
Asterism	259890012	259889850	17208288000
Universae	18712080814×10^6	187120892×10^8	94297796×10^4
q/p	13.96	13.36	156.21

Table 7. Rate of mean motion of planets per day. The quantities in the upper line in each row in the third and fourth columns are in sexagesimal system, and the ones in the corresponding lower line are in decimal system.

Planets	Modern value (*Lahiri*)	Brahmagupta *Sripati Bhaskar*	Samanta Chandra Sekhar
	° ' "	° ' "	° ' "
Sun	0 59 08.2	0 59/8/10/21 59 8.1725	59/8/10/24/12/30/4/0/4 59 8.1733912
Moon	13 10 35.0	13/10/34/53/0 13 10 34.8833	13/10/34/52/03/49/ 08/02/16/10/11 13 10 34.8677274
Mars	0 31 26.5	0/31/26/28/7 31 26 . 4686	0/31/26/30/06/47/ 44/32/49/03/04 31 26.5018876
Mercury	4 05 32.4	4/05/32/18/28 4 5 32 . 3077	*
Jupiter	0 04 59.1	0/0459/9/9 04 59 . 1525	0/04/59/05/37/0/ 36/41/17/01/51 0 4 59.0936139
Venus	1 36 07.7	1/36/7/44/35 1 36 7.74305	*
Saturn	0 02 01.9	0/02/0/22/51 2 0.380833	0/02/0/26/55/02/ 53/21/02/04/54 0 2 0.4486244
Moon's	– 0 03 10.6	0/03/10/48/20 03 10.8055	0/03/10/47/40 40/27/11/25/13/30 0 03 10.7946317

* Mean of sighrochcha for Mercury and Venus are given as 4°/05'/32"/16/07/59/43/42/44 and 1°/36'/07"/ 47/57/50/39/32/31/35 respectively.

Table 8. Ayana Chalan rates from various sources.

Sl. No.	Astronomical work	Annual rate
1	Surya Siddhanta	54"
2	Soma Siddhanta	54"
3	Sakalya Siddhanta	54"
4	Laghu Vashistha	54"
5	Parasara Siddhanta	52.35"
6	Aryastha Stika	46.25"
7	Munjala (quoted by Bhaskar)	59.9"
8	Bhasvati	60"
9	Grahalaghava	60"
10	Siddhanta Darpana	57.615"

essential for the calculation of the position of planets which is warranted due to his special model of the solar system to be discussed later. It must be remembered that very accurate rates are necessary for correct calculation of the mean position.

After incorporating the usual corrections in the calculation of planet positions, one may apply further corrections enlisted in tables given by Chandra Sekhar for each planet for hundred million (one arbuda) years. There are as many as fifty-five tables, each on the average having fifty numbers, some times given upto five places in the sexagesimal system. These tables look to be a challenge for one's unaided computational skill.

We confess out inability to enter into the intricate procedure in the text on calculation of the planetary positions, eclipses, alignments, transit and phases. However, we would like to touch upon only Samanta's calculation of the "ayan chalan" (precession of Earth's axis) rate. This is an important parameter for fixation of longitudes of celestial bodies. A detailed account of Samanta's calculation and its comparison with other traditional works is given in the introduction to Siddhanta Darpana (Ray 1899). As a summary, we quote the rates given by various works / authors in Table 8.

The modern value of the precessional rate is, however, 50".3 per year. Therefore, it can be seen from the table that all the Indian data seem to be in disagreement with this value excepting that of the Parasara Siddhanta which looks apparently closer. But Ray gives a solution to this puzzle by pointing out that the Indian astronomers take the sidereal year for calculation of rate of precession in contrast to the tropical year, taken in the West. It is well known that the assumed sidereal year is longer by some minutes during which the Sun advances by 8".4. When this correction is taken into account on Samanta's value, the rate of precession turns out to be 49".179, in near agreement with the modern value. We have checked with a current almanac (Khadiratna 1995) and found that a rate of 57".628 per year is still in vogue in the calculation.

Finally we would like to point out a couple of facts of pure mathematical interest from Siddhanta Darpana. Samanta has stated that Bhaskar and others have taken 22/7 as the ratio of the

circumference and diameter of the circle (= Π). But he has taken the values as 3927 / 1250 and 600 / 191 in the text at various places. These values are definitely more accurate. He has given a new method of finding the cube root of numbers, different from that of Bhaskar.

5. Methods of measurements and instruments

Completely unware of the scientific and technological developments in the west, Samanta Chandra Sekhar employed traditional methods for astronomical measurements. Very often, he has constructed new instruments and used them for own observations. It is a remarkable point that, Jai Singh (1688 - 1743) influenced by his western contact, built a number of observatories in the northern parts of the country and erected rather large sized instruments for naked eye observations (Sharma 1995). In contrast, Samanta Chandra Sekhar, who came about 150 years later, fabricated simple and mostly portable devices with which he could make very accurate observation.

Chandra Sekhar gives detailed description of construction and use of various instruments, (yantras) in the 20th chapter of Siddanta Darpana. In this respect he is unlike his predecessors, who hardly mention even, the name of the instruments used. It is worth mentioning here that recently an attempt has been made (Ohashi 1987, 1994) to shed light on instrumentation in classical Indian astronomical works.

Chandra Sekhar's instruments can be broadly classified into three categories i.e. (i) Instruments for measuring time, (ii) armillary sphere and (iii) versatile instruments. There is a description of as many as ten different instruments in Siddhanta Darpana for measuring time. These include the sun-dial like Chakra Yantra (fig.1), Chapa Yantra (fig.2), Golardha Yantra (fig.3) and a water clock (swayambaha yantra) (fig.4). The armillary sphere (fig.5) has been used by the Greek, Arab and Hindu astronomers. But what is interesting with Samanta's device is that he prescribes ways to construct it with wood and bamboo chips. He has described the construction and use of a multi compartment armillary sphere (Bahu Kaksha Gola Yantra) also.

The instruments that were of versatile use are, the Sanku (gnomon) and the Mana Yantra. They could be used to determine the local time, latitude, altitude, zenith distance, declination of sun, its position in the zodiac, angular separation between celestial objects and even height and distance of mountains. In fact, the Mana Yantra, is the most talked of instrument of Chandra Sekhar. Even the students in the primary schools in Orissa know as a legend that Samanta Chandra Sekhar was a number of times put to test by being asked to measure the separation between two celestial objects, their elevation or the height of a distant mountain. Chandra Sekhar came out successful all the times invariably with the use of his Mana Yantra (cross-bar). This instrument is a "T' shaped arrangement of wooden rods of measured length, graduated according to prescription (fig. 6).

A couple of these instruments used by Samanta are preserved in Orissa State Museum. Some of these instruments have recently been fabricated and exhibited at the Regional Science Centre, Bhubaneswar (Sahu 1995). These instruments, in today's standard are undoubtedly crude. But using them, Chandra Sekhar could arrive at results, almost agreeing with modern measurements,

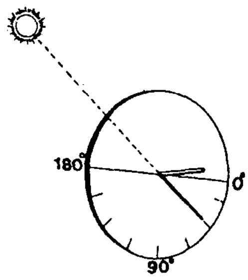


Figure 1. Chakra Yantra for measurement of time.

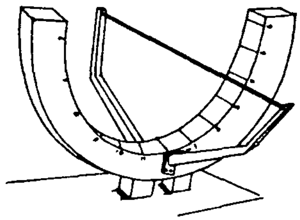


Figure 2. Chapa Yantra for measurement of time.

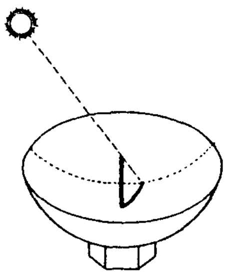


Figure 3. Golardha Yantra for measurement of time.

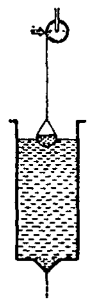


Figure 4. Swayambha Yantra - a water clock for measurement of time.

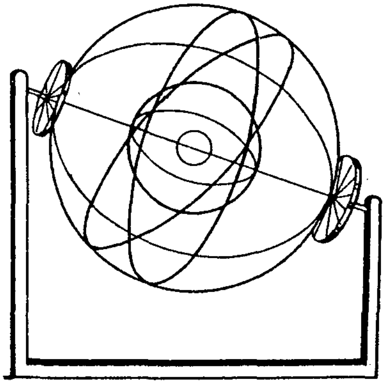


Figure 5. Gola Yantra for measurement of planetary position.

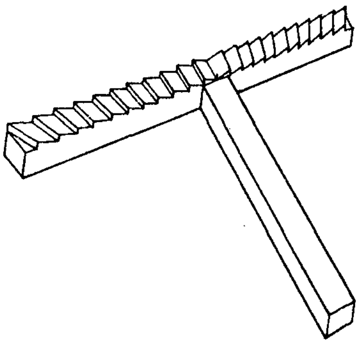


Figure 6. Mana Yantra - a versatile instrument for measurement of various astronomical quantities (See Text).

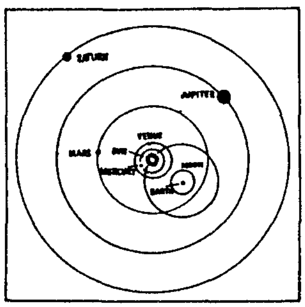


Figure 7. Samanta Chandra Sekhar's model of the solar system.

primarily due to the skill attained through long years of dedication and practise.

Samanta Chandra Sekhar gives methods based on geometry (parilekha for observation of events like eclipses, conjunctions and even phases of the Moon. We do not see description or mention of such methods in any earlier work. The prescriptions look a little complicated. It needs closer investigations.

6. Theory and models

Samanta Chandra Sekhar had his own concepts of the solar system and the universe, based on his own observations and he has given them mathematical formulations, wherever necessary. As indicated earlier, he postulated the concept of parochcha for certain planets.

The most important contribution of Samanta Chandra Sekhar to the planetary models is a picture of the solar system, entirely different from those of his predecessors. Of course, like all other Hindu astronomers he supports a geocentric hypothesis. However, his model has the novel feature that planets - Mars, Mercury, Jupiter, Venus and Saturn go round the Sun and the Sun moves around the Earth together with these companions. Thus, he has assigned heliocentric motion to the planets (fig.7). The central idea of this model is contained in the following slokas of Siddhanta Darpana.

तत्रमध्यम - मार्त्तण्ड : परितोमण्डलंभुव :
भ्रमन् ताराखेचराणां कक्षामधायस्थ उच्यते ।

तं भ्रमन्तो महीजाद्यास्तत्सङ्गेन भुवं पुन :
परिक्रामन्ति यत्तस्मात् स प्रोक्त : सर्वकर्षक : ।

मन्दापकर्षणं हित्वा सदार्कात् समद्रगा :
यान्ति ताराग्राहा : प्राची भचक्रमनुनक्षते ।

(S. D. Ch. V Slokas 6, 7 & 17)

Incidentally an identical model of the solar system was proposed by Tycho Brahe in the West. A recent work by Ram Subramanian et al. (1994) suggests that a similar model of the planetary system was given by Nilakantha Somasatvan of the Kerala school in 1500 A.D.

The two other remarkably different views of Samanta Chandra Sekhar from that of the earlier Hindu astronomers, are : (i) Fixation of the mean line for zero terrestrial longitude and (ii) Fixation of time of calculation of ahargana.

These are important factors in traditional astronomy. It is well known that the longitude of Ujaini was assumed as the mean line and the sunrise at this longitude was taken to be the initial time of the epoch in all the earlier works in India. But Chandra Sekhar has accepted a Lanka (not the present Sri Lanka) as the place of mean longitude, collinear with Junagarh of Gujarat and Jalabadpur (Jalalabad) of Afghanisthan, with modern longitude 70° 30' (E) and 70° 26' (E)

respectively. Therefore, modern 70° 31' must have been taken as the mean line which further agrees with local time difference (desantar correction) for specific places (Shastri 1975).

As mentioned above, Samanta Chandra Sekhar like most of our traditional astronomers believed in a static Earth. But probably he was informed of the heliocentric picture prevalent in the West. But he did not accept it. Rather he has devoted a full chapter (Ch.17 with one hundred and sixty one slokas) in support of his view. One may look at the conviction and intellectual courage of the man, who poses, in the concluding stanza of Siddhanta Darpana, a direct challenge to the western astronomers (And it was during the British Raj!)

ब्रह्माण्डाखण्डभाण्डस्थिरतरधरणीमण्डलभ्रान्तिशौण्ड ।
प्रोद्दण्डैलण्डदन्ताबलबलदलनाकुण्ठकण्ठीरबथी : ॥
सोहंयं नीलाद्रिसिंहान्वयबदनदरीनिर्गतः प्राप्तदुर्ग : ।
स्फीत स्वख्यातिरस्तु प्रथमबिगणितस्कन्धसार : प्रबन्ध : ॥

(S. D. Ch. XXIV sloka 158)

7. Conclusion

Enormous is the contributions of Chandra Sekhar to astronomy as recorded in Siddhanta Darpana. In fact, the treatise is a Siddhanta, a Tantra and a Karana, all in one, since Samanta has calculated and tabulated "aharagana" and mean planets in three systems with respective times starting from the beginning of the Kalpa, Kaliyuga and the day of commencement of writing Siddhanta Darpana. Chandra Sekhar has declared, his formulae will remain valid upto ten thousand years. Thereafter, if the formulae fail to agree with observations further corrections given in the tables are to be taken into account to keep the work valid upto ten crore years to come. It needs closer investigation again to test Samanta's predictions for long future with modern calculations.

A century has passed since Samanta passed away in 1904 living through poverty and struggle, muckery and dyspecpia with colic. The only consolation to this dedicated scientist during his life time was the title of Harichandan Mahapatra conferred upon him by the Gajapati king of Puri in 1870 when his prescriptions were adopted for observance of rituals in the Jagannath temple. The practice has been continuing since. Lately in 1893, the British Government conferred the title of Mahamahopadhyaya upon him and granted him a monthly pension of Rs.50/- only.

In the mean time ten decades have passed since the publication of Siddhanta Darpana. But it is a pity that the author and his work had remained almost unknown beyond the boundary of Orissa state. It is a matter of relief that Chandra Sekhar has found mention recently in two works on astronomy (Kochhar and Narlikar 1993; Sriram 1993). It may be noted that Siddhanta Darpana is not a work of historical curiosity only. Even today, it serves as the basis of almanac preparation in Orissa and has practical value for positional astronomy.

Ray has drawn a nice parallelism between Samanta Chandra Sekhar and Tycho Brahe. But he does not give the contrast. Tycho, in recognition of the merits of his work gained the friendship of

the king of Denmark. He was given a full island with an observatory, built under the royal patronage. He was succeeded by a student like Kepler who made use of the fabulous data collected by Tycho and formulated the most famous three laws of planetary motion. But Samanta worked single handed and unaided, under most adverse conditions. Nevertheless, Siddhanta Darpana stands as a monumental piece of work in traditional astronomy. Chandra Sekhar's position among great Hindu astronomers is yet to be fixed. Nature[1] (1899) commented. "Prof. Ray compares the author very properly to Tycho. But we should imagine him to be greater than Tycho". It will probably not be an exaggeration to say that Samanta Chandra Sekhar belongs to the class of the four great Hindu astronomers, Aryabhata, Varahamihira, Brahmagupta and Bhaskara.

In view of the quality of data obtained by Samanta Chandra Sekhar through naked eye observations, which are comparable to those of the modern astronomy based on telescope and other optical devices and also the predictive potential of his work expected to remain valid for thousands of years to come, it may be fair to state that he is probably one of the greatest naked eye astronomers of the world. In fact, Knowledge[2] (1899) comments to this effect, "The work is of importance and interest to us, westerners also. It demonstrates the degree of accuracy which was possible in astronomical observation before the invention of the telescope".

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